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Transient ship synoptic reports : an evaluation of their contributions to a fog study of 19 August - 5 September 1974, and 1-5 December 1975.

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TRANSIENT SHIP SYNOPTIC REPORTS, AN EVALUATION OF THEIR CONTRIBUTIONS TO A FOG STUDY OF 19 AUGUST-5 SEPTEMBER 1974, AND 1-5 DECEMBER 1975

Joseph Austin Schrock

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

TRANSIENT SHIP SYNOPTIC REPORTS, AN EVALUATION OF THEIR CONTRIBUTIONS TO A FOG STUDY OF 19 AUGUST-5 SEPTEMBER 1974, AND 1-5 DECEMBER 1975

Joseph Austin Schrock

June 1976

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Over 1400 ship reports occurring off the coasts of California, Oregon, and Washington during two weeks in August 1974 and one week in December

1975 were analyzed. The visibility-weather group elements of the ship reports along with daily NOAA II satellite photographs were used to establish fog location and boundaries. Other synoptic parameters such as air temperature, pressure patterns and sea surface temperature were studied in an attempt to determine reasons for marine fog development. An evaluation of the credibility and reliability of transient ship synoptic reports also was made. It was found that of all the reports indicating fog, 36 percent were in violation of the World Meteorological Organization (WMO) procedures and definitions.

Results indicate that although there are a significant number of inconsistencies and problems associated with ship reports, they can provide numerous products useful in establishing offshore marine fog conditions. These products, fog location charts, sea surface temperature charts, air temperature minus sea surface temperature charts, and surface trajectories, do lend support to existing synoptic models of the fog formation processes along the California coast.

Transient Ship Synoptic Reports, An Evaluation
of Their Contributions to a Fog Study of
19 August-5 September 1974; and 1-5 December 1975

by

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Submitted in partial fulfillment of the
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I. INTRODUCTION

Marine fog has been and continues to be a subject of intense research. Numerous approaches over a large range in scale have been utilized in an attempt to define, understand, and forecast marine fog. The need for a total understanding of marine fog is of particular importance to naval operations on the high seas and in coastal waters. Wheeler (1974) discusses both strategic and economic losses to the Navy as a direct result of reduced visibilities caused by marine fog. With losses in fog related accidents on the order of 113 million dollars and 74 lives in only a five year period (1969-1973), the United States Navy is obviously in need of a more accurate means of analyzing and predicting the formation and dissipation of marine fog.

There are various ways to approach a study in marine fog. Misciasci (1974) stated that there are three main approaches: climatological, statistical-numerical, and synoptic. Although these approaches are all encompassing, they are quite general and may not reflect directly to the reader the numerous methods of research used in the past and the ones currently being employed. In order to be more descriptive, the approaches used to date will be classified in the following manner: (1) Microphysics and physics of fog formation and dissipation, (2) Statistical-numerical modeling and forecasting, (3) Depiction of fog areas over the open ocean from satellite information, (4) Marine fog climatology, (5) Synoptic modeling and forecasting, and (6) Classification and descriptive definitions. These approaches will be discussed in the next chapter. It must be

emphasized that these six categories are not independent of one another, but that they are all interrelated. The sole intent of this classification is to give the reader an indication of the main subject content found in the literature.

The approach used in this study is that of synoptic modeling and forecasting. The majority of the research to date under this category has considered only fixed point locations (coastal stations and ocean weather stations) where a time series of data development could be studied and analyzed. This study is unique in that it is using as a data base transient ship synoptic reports where neither fixed point nor time series analyses can be employed.

The purpose of this study is (1) to estimate the credibility and reliability of transient ship data used in a synoptic approach to a marine fog study; (2) to determine the validity of the representation of the fog conditions, locations, and boundaries from these data; (3) to investigate how the products from these data may (or may not) support existing synoptic models of the fog formation processes along the California coast; and (4) to determine if offshore marine fog conditions may be inferred from regularly available observations along the coast.

The area of investigation was from the west coast of the United States out to 130° west longitude, and from 30° to 50° north latitude. All transient ship reports within this area were collected and analyzed for two separate time periods: 19 August - 5 September 1974 and 1-4 December 1975. The first time period was chosen primarily to determine the offshore marine fog conditions to supplement the coastal study of Peterson (1975). The other period was chosen so that winter time marine fog development could be compared to summer development.

II. BACKGROUND

A. DATA SOURCES

Considering the size of the oceans and the lack of a dense fixed network of marine observation sites, the study of fog over the open oceans is a difficult task. One must either put to sea and collect his own data, or rely on the observations of other sea going vessels. It was realized over 100 years ago that the only possibility of getting meteorological observations over the open ocean on a somewhat regular basis was to ask for the cooperation of merchant, military, and fishing vessels (Roll, 1965). This marked the beginning of the transient ship synoptic report. Today in the course of an average peacetime year, more than 400,000 observations are received from vessels representing every maritime nation and reaching every quarter of the globe (U. S. Coast Pilot 7, 1975). The collection of these observations is conducted on a voluntary, nonprofit, cooperative basis. The obvious disadvantages of these observations are that they are basically confined to the main sea routes and that they are usually made by an untrained observer. The meteorological observations of these transient ships have always been only a secondary task (the primary being fishing, etc.) with only the minimal surface and no upper air data reported. With the advent of trans-oceanic aviation, there was an urgent need of weather information to an extent not available from the transient ship reports. Then with a further increased demand for more detailed meteorological data during World War II, a fixed network of 13 ocean weather stations was established in 1946 by the International Civil Aviation

Organization (Roll, 1965). The great advantage of the ocean weather stations is that for the first time a continuous time series of detailed surface and upper air data at one fixed location at sea could be maintained. Since this was an important mission of the vessel plus the fact that observations were made by well trained personnel from a well equipped ship, data should be more accurate than from transient ships.

Prior to the advent of the ocean weather stations, the only data sources were from coastal land stations, scientific research cruises, and transient ship reports. Research cruises were costly and time consuming; and transient ship reports were limited in value since they lacked upper air data and dense geographic distribution. Therefore, most of the early studies concentrated primarily on coastal fog since coastal data were more plentiful and more readily available. The ocean weather stations added a new dimension to marine fog research. Several papers, such as Ogata and Tamura (1955) and Misciasci (1974), were based on data from this source. Over the past decade, weather satellite data (visual and infrared) has augmented all aspects of marine fog studies. Thus for any study on the analysis of marine fog, there are five sources of workable data. They are from the transient ship reports, the ocean weather stations, scientific research cruises, land station observations along the coast, and weather satellite information. The type of approach used in a marine fog study is influenced (if not determined) by the amount, sophistication, and source of available data.

B. SYNOPTIC MODELING AND FORECASTING

The synoptic modeling and forecasting approach is concerned with measuring the meteorological and oceanographic parameters on a real time basis

and determining how their interrelationships initiate the formation and dissipation of fog. These parameters are also examined for forecasting relationships. The most classic example of this approach is that of Leipper (1948) in his analysis of coastal fogs at San Diego, California, during the winter period from October through April. His study lead to the conclusion that nearly all of the fog situations in the San Diego area developed in a systematic manner over a period of several days.

Leipper devised a model which described the manner of fog development in four different stages. The first stage is initiated when the North Pacific subtropic high pushes inland over northern California. The subsiding air which is dry and adiabatically warmed flows offshore and over water that is much colder causing an inversion to form at the surface. This inversion restricts the vertical movement of moisture and allows the thin marine layer to approach saturation. The fact that the warm layer above is also dry is very important, for this will allow rapid cooling of the surface layer by radiation once fog is formed. In the second stage, the easterly offshore flow of the warm dry air decreases allowing the offshore air to remain relatively stationary. With the conduction of sensible heat downward, a surface inversion is formed, and the lowest air layers become nearly saturated because of increased evaporation from the sea. The third stage occurs when normal northwesterly airflow and sea-breeze regime returns. Fog is formed as the relatively warm, nearly saturated thin surface layer flows over the cold, upwelled tongue of surface water existing just offshore from San Diego. Once the fog is formed, radiation cooling becomes very important and is responsible for intensifying and maintaining the fog layer. The radiation causes the nearly stagnant fog layer to become several degrees cooler than the sea

surface because of an increase in evaporation and radiational cooling from the top of the fog layer. This action causes the temperature lapse rate within the fog layer to be nearly dry adiabatic and lifts the base of the inversion off the surface. The fog layer increases in depth gradually from day to day, causing the base of the inversion to be lifted also. On the first day when the fog layer, still relatively thin, arrives onshore, the heat of the land is sufficient to dissipate the fog. Stage four is reached when the fog layer grows to such a thickness (approximately 400 feet or more) that it cannot be dissipated at the coast and will move further inland with the afternoon sea breeze before dissipation. During this stage, fog is present over the sea both day and night. Eventually, the fog layer below the inversion reaches a thickness (approximately 1300 feet in San Diego) beyond which there is insufficient cooling to create a full layer of fog. This marks the end of the fog sequence and the beginning of the stratus regime. The entire sequence described by this model usually extends over a period of about five days.

Leipper was also interested in forecasting the occurrence of fog in the San Diego area through use of observations related to key processes in the model just described. He defined three nondiurnal indices which provide a necessary but not sufficient condition for formation of fog at the airport in San Diego. (Nondiurnal means in this case that diurnal variations do not affect the index values.) These indices are:

1. Height of the Inversion Base: The height above which the air temperature increases with height at the most rapid rate on the North Island (San Diego) morning radiosonde observation (RAOB).
2. Temperature index: The quantity (T_a - T_w) where, if an inversion exists with base below 3000 feet, T_a is highest air temperature

above the inversion base on the morning raob or, if no inversion exists with base below 3000 feet, T_a is the surface air temperature on the morning raob; T_w is the sea surface temperature at the end of the Scripps pier (La Jolla).

3. Moisture Index: The quantity ($DP_{1630} - T_w$) where DP_{1630} is the surface dew point at Lindbergh Field (San Diego) at 1630 PST and T_w is the sea surface temperature on the preceding fog day.

He placed ranges on these indices for favorable conditions of fog formation. The ranges are: for height of the inversion base, 0 to 1300 feet; for temperature index, any positive value; for moisture index, any positive value or any negative value between 0 and -5°C. Leipper's 1948 fog development model and his method of using indices for the forecasting of fog represents one of the first successful attempts objectively to describe and forecast marine fog. His ideas have been incorporated into the United States Navy forecasters handbook used in the San Diego area. Leipper's 1948 model also has been extended to other seasons and points further north. Leipper (1968) pointed out that the fog development studied by Stephens (1965) in the Los Angeles area was similar to his model study in the San Diego area. Rosenthal (1972) described the synoptic situation associated with the formation of fog and stratus in the Point Mugu area (northwest of Los Angeles) by conditions very similar to Leipper's 1948 model.

Peterson (1975) extended the model even further north in his study of fog sequences on the central California coast north of Point Conception. Peterson's model, consisting of three stages, synoptically is quite similar to Leipper's 1948 model but differs in that is concerned with sequences along a large segment of the central California coast (vice

only the San Diego area) during late spring, summer and early fall (vice the winter period). Peterson presents much detail in his developmental model (perhaps more than his data support).

The synoptic approach also has been used by researchers studying observations collected at sea. Taylor (1917) spent six months on the whaling ship Scotia analyzing the formation of marine fog in the Grand Banks off Newfoundland. He concluded that most of the fogs were formed due to the cooling of nearly saturated air as it passed over the cold areas of the sea. Taylor also made an attempt to devise a scheme for forecasting fog empirically with the use of moisture diagrams, but met with only limited success.

According to Roll fog studies at ocean weather station Extra (39°N, 153°E) were conducted by Ogata and Tamura(1955). Their study, statistical in nature, examined the observations at this fixed point over a continuous time series to determine the synoptic conditions which were favorable for the formation of fog. Misciasci(1974) conducted a similar study with ocean weather stations Quebec(43°N, 167°W)and Sierra(48°N, 162°E). All observations taken at these two points during the months of May and June 1953 were analyzed. Although his results may be of only local significance, some may also apply to fog development on the North Pacific Ocean in general and perhaps to coastal areas as well. Misciasci found that of all the observations reporting fog, 81% reported visibilities of less than 1/2 mile. His data indicated that no particular time of the day was more favorable for fog formation than any other. With the idea of predicting fog utilizing point parameters such as air temperature (T_a), dewpoint temperature (T_d), and sea-surface temperature (T_w), his analysis shows that($T_a - T_w$) does not give a good indication of differentiating between fog or no fog conditions.

whereas $(T_a - T_d)$, a measure of moisture content, and $(T_d - T_w)$, a measure of relative moisture content, do give a good indication and are critical to any fog forecasting scheme. Since Misciasci worked with ocean weather station observations, he had available upper air data, and found that the thickness of the inversion and the duration of air mass fog are related.

Grisham (1973) did a similar statistical analysis of synoptic parameters. His study differed from Misciasci's in that he used transient ship reports as a data base. Grisham analyzed 16,000 synoptic ship reports for the month of July 1972, over the whole North Pacific Ocean, in an attempt to find favorable indices for fog formation. He found that 87% of the fog cases had a dewpoint sea-surface temperature spread between -6° and 1°C, and an air, sea-surface temperature spread between -3° and 3°C. He also found that 81% of the fog cases reported visibilities less than 1 nautical mile and 89% less than 1/2 nautical mile.

The Calspan Corporation (Mack et al, 1975) conducted an intensive three year study of the physics and micrometeorology of marine fog occurring off the California coast. Their study was performed jointly with the Naval Postgraduate School, Monterey, California, aboard the Acania, the oceanographic research vessel assigned to the School. Through their investigations, they determined that at least five distinctly different types of fog off the California coast form in response to the interaction of large scale systems to a variety of local influences. The types of fog are:

1. those which develop as a result of lowering stratus clouds;
2. those which form in coastal valleys and flow out onto protected bays via a land breeze;
3. those which form over patches of warm water;
4. those associated with mesoscale convergence;

5. patches forming in an organized manner downwind of areas of cold water.

All types, though, do have several features in common. There is a need for a capping inversion low enough to permit the lower marine layer to approach saturation. Although turbulent heat exchange is required to initiate the formation of fog, it cannot be responsible for the growth and persistence of the fog. Radiational cooling is the mechanism responsible for growth and persistence of the fog for all five types. They made no attempt at any forecasting scheme.

C. MICROPHYSICS AND PHYSICS OF FOG FORMATION AND DISSIPATION

With increased sophistication of research equipment and with the increase of scientific cruises, the microphysical and physical approach to marine fog formation has become more intensive. This approach is very similar to the synoptic approach in that both are trying to establish how and why the fog was formed. This approach, though, is concerned more with the smaller scale microphysical features (such as fog droplet size spectra, aerosol size spectra) plus mathematical descriptions of turbulent theory in the dynamics of air-sea interaction. The "Fourth Annual Marine Fog Investigation Program" meeting held in Reno, Nevada on 6-7 January 1976 suggested that at least 80 percent of current marine fog research is being conducted on the microphysical level. Goodman (1975) in her paper "The Microstructure of California Coastal Fog and Stratus" stressed her observations showed that despite large differences in the synoptic scale features, the microphysical development of fog in each case was quite similar, indicating the importance of synoptic scale studies to determine how varying synoptic conditions lead to the same microphysical development. The study to be described will not include any microphysical development.

D. STATISTICAL-NUMERICAL MODELING AND FORECASTING

The development of modern day computer technology has made other approaches to fog studies feasible. The statistical-numerical modeling and forecasting approach depends almost entirely on the computer's ability to handle and process large volumes of data. Nelson's study (1972), "Numerical-Statistical Prediction of Visibility at Sea," is an example of a statistical type approach. By using regression analysis, he attempted to establish a linear functional relationship between observed visibility and 13 meteorological and oceanographic parameters generated from each of the 2800 marine surface observations analyzed. He met with little success for two reasons basically. One was that the regression equations for visibility based on conventional marine surface observations were not of sufficient accuracy. The lack of accuracy he attributed to the poor estimates of visibility at sea by relatively untrained observers. (This particular problem will be discussed later on in this study.) The other reason was the poor quality of the numerical forecasts of the temperature and humidity fields.

As an example of a modeling type approach, Barker (1975) improved an earlier numerical fog and stratus forecast model that was developed in 1963, by reworking and incorporating new parameters in the maritime boundary layer equations. Results from the numerical experiments that he conducted compared well with the generally accepted theories.

Fleet Numerical Weather Central (FNWC), Monterey, California uses this approach in their fog occurrence forecasts. Their operational product is based on the statistical processing of certain related parameters within FNWC's Primitive Equation Model and is provided twice daily (0000 and 1200

GMT) in a probability of fog format for forecast intervals up to 72 hours (Hale, 1975). According to Renard et al (1974) FNWC's product, which presently is the only fog occurrence forecast to cover all the marine areas of the Northern Hemisphere, lacks a reliable climatological fog frequency parameter and is not believed to be at a level that is operationally acceptable.

E. MARINE FOG CLIMATOLOGY

A fourth approach to marine fog analysis is that of marine fog climatology. This approach gathers all available data in a particular area or location to determine monthly or sometimes seasonal frequency of fog occurrence. There are numerous sources for both regional and whole ocean marine fog climatologies. Renard et al (1974) discuss in detail how the various sources of existing climatologies for marine fog over the open ocean, including a source widely used by the United States Navy, are poorly documented and, in some instances, are incorrect. Because of this questionable accuracy, Renard et al (1974) and Willms (1975) developed a unique approach to deriving marine fog frequencies during the summer season for the North Pacific Ocean. They derived a statistical scheme which uses the visibility, present weather and past weather information from the transient ship and ocean weather station synoptic reports to identify the presence and to estimate the duration of marine fog. Their resulting computerized program is called SSR (Synthesis of Synoptic Report information to derive marine-fog occurrences) (Willms, 1975). Their success appears to be quite favorable in that by placing the emphasis on the observation of fog by considering the entire visibility-weather group (visibility, present weather and past weather) instead of just visibility

as was done in previous climatologies, a more accurate (based on actual ship logs) and detailed product is formed.

F. DEPICTION OF FOG AREAS OVER THE OPEN OCEAN FROM SATELLITE INFORMATION

The approaches to the analysis and forecasting of marine fog discussed thus far are all limited in that they depend on data that is extremely sparse and widely spaced, and where no data is present, climatological values of questionable accuracy must be used. Therefore, any forecast based on this type of data is also of doubtful accuracy. Depiction and forecasting of fog areas over the open ocean must eventually be developed from the most logical source now under development, weather satellite observations. Satellite observations have been used for several years in strictly a visual and extremely qualitative sense. In the most general way, if an area was clear, there was no fog there. If an area was cloud covered, there was no way of distinguishing if the cover was fog or stratus. Wallace (1975) and Hale (1975) have both addressed this problem. Their object was to develop a method for evaluating digital visual and/or infrared data from weather satellites to discriminate fog from no-fog areas. A statistical approach was used to identify critical brightness (visual mode) and temperature (infrared mode) count values to specify fog/no-fog boundaries. Transient ship and ocean weather station reports were used as ground truth data. This approach has not demonstrated great success so far.

G. CLASSIFICATION AND DESCRIPTIVE DEFINITIONS

The final approach is the classification and descriptive definitions of marine fog. This approach, used by those authors whose desire it is

to give the reader only a general knowledge of fog and related phenomena, is found mainly in descriptive meteorology and oceanography textbooks. Probably the most often quoted source is General Meteorology by Byers (1959). He classified fogs into 11 categories according to the easily recognizable meteorological processes which caused them. His categories are sea fog, land-and-sea breeze fog, tropical-air fog, steam fogs, ground fog, high-inversion fog, advection-radiation fog, upslope fog, prefrontal fog, postfrontal fog, and front-passage fog. Donn (1975) also classified fogs according to the meteorological processes which caused them, but his categories are not as detailed and include radiation fog, advection fog, frontal fog, and upslope fog. According to Fleagle (1953), terms as advection fog, radiation fog, etc., may describe certain features of the weather situation, but they do not help very much in understanding the physical processes which bring about the fog. He claims that fog classification should be based on the physical processes responsible for producing saturation and include only two major types: cold surface fog and warm surface fog. It is evident that no universally accepted classification exists. Unfortunately, this also applies for the definition of fog. The most general definition of fog, "a visible aggregate of minute particles of water based at the earth's surface, which reduces horizontal visibility" (U. S. Departments of Commerce, Defense and Transportation, 1969a) is universally accepted. The problem is with the magnitude of reduction in horizontal visibility and the use of such terms as heavy fog, light fog, haze, or mist. Byers (1959) uses the following definitions:

Fog - a suspension of very small water droplets in the air, generally reducing the horizontal visibility at the earth's surface to less than 1 km.

Mist - a suspension in the air of microscopic water droplets or wet hygroscopic particles reducing the visibility at the earth's surface to not less than 1 km.

Haze - a suspension in the air of extremely small dry particles invisible to the naked eye and sufficiently numerous to give the air an opalescent appearance.

Byer's use of the word "generally" in his fog definition implies that fog can still exist with a visibility above 1 km, in which case it would be no different from mist. Also noteworthy is that he places no visibility restriction on haze, and that he uses no upper visibility limit on mist.

The Glossary of Meteorology (1959) uses the following definitions:

Fog - A hydrometeor consisting of a visible aggregate of minute water droplets suspended in the atmosphere near the earth's surface. According to international definition, fog reduces visibility below one kilometer. Fog differs from cloud only in that the base of fog is at the earth's surface while clouds are above the surface. Fog is easily distinguished from haze by its appreciable dampness and grey color. Mist may be considered as intermediate between fog and haze.

Mist - 1. According to international definition: a hydrometeor consisting of an aggregate of microscopic and more-or-less hygroscopic water droplets suspended in the atmosphere. It produces, generally, a thin, greyish veil over the landscape. It reduces visibility to a lesser extent than fog.

2. In popular usage in the United States, same as drizzle.

Haze - Fine dust or salt particles dispersed through a portion of the atmosphere; a type of lithometeor. The particles are so small

that they cannot be felt or individually seen with the naked eye, but they diminish horizontal visibility and give the atmosphere a characteristic opalescent appearance that subdues all colors.

Noteworthy here is that fog has a definite upper limit of 1 km visibility, mist has no upper limit visibility, and haze has no visibility limits at all.

Haynes (1947) uses the following definitions:

fog - minute water droplets suspended in the atmosphere, reducing horizontal visibility to less than 1000 meters.

heavy fog - when fog is present and the visibility is less than 500 meters.

moderate fog - when fog is present and the visibility is between 500 and 1000 meters.

light fog - when fog is present and the visibility is 1000 meters or more.

dry haze - dust or salt particles which are dry and so extremely small that they cannot be felt or discovered individually by the unaided eye; however, they diminish the visibility and give a characteristic smoky (hazy and opalescent) appearance to the air.

damp haze - minute water droplets suspended in the atmosphere with reduced visibility, 2000 meters or more, usually considerably more.

Haynes' fog definitions are the same as those in the Glossary of Meteorology except that he put limits on fog intensity (heavy, moderate, light) with light fog defined the same as mist in the Glossary. Haynes also makes two classes of haze with damp haze comparable to his light fog.

Donn (1975) defines fogs according to their effect on visibility in the following manner:

description	objects not visible at
dense fog	45 meters
thick fog	180 meters
fog	450 meters
moderate fog	900 meters
thin fog	1800 meters

Donn's definitions are totally unique. They have not been used elsewhere in the literature.

The Federal Meteorological Handbooks, Nos. 1 and 2, (U. S. Departments of Commerce, Defense, and Transportation, 1969a,b) use the following definitions:

fog - a visible aggregate of minute particles of water based at the earth's surface which reduces horizontal visibility below 1000 meters

light fog - a visible aggregate of minute particles of water based at the earth's surface, which reduce horizontal visibility to not less than 1000 meters (5/8 mile) and not greater than 6 miles

haze - a suspension in the air of extremely small, dry particles invisible to the naked eye and sufficiently numerous to give the air an opalescent appearance. No visibility limits are involved

mist - a European term meaning the same as light fog

As a member of the World Meteorological Organization (WMO), the United States has certain commitments with regard to the coding of surface synoptic reports (land and ship). The procedures and requirements adopted by the

organization are incorporated in the Federal Meteorological Handbooks and should be complied with by all United States agencies of the Departments of Commerce, Defense, and Transportation. This compliance is needed so that each meteorological phenomenon can be represented without ambiguity by a single code or symbol which has the same meaning nationally as well as internationally. Standardization in the reporting of fog still does not exist mainly because of ignorance of these definitions by some weather observers, plus the fact that visibility is extremely difficult to measure, especially at sea. Of all the ship reports used in this study that reported fog, 36 percent were in violation of the WMO procedures and definitions. Real problems created by the lack of standardization arise when trying to interpret recorded observations if they aren't properly defined.

III. DATA

A. DATA SELECTION

Coastal fog studies have always alluded to offshore conditions and how they are responsible for fog at the coastal observation sites. Researchers only infer what these offshore conditions are from known observations along the coast. One such study was that of Peterson (1975) where he studied meteorological observations on the central California coast in an attempt to determine day-to-day sequences of fog development. Peterson recognized that at-sea oceanographic and meteorological data are needed for an entire fog/stratus development model, but was unable to incorporate any offshore analysis into his model because of time considerations. This study will attempt to determine the offshore conditions during one of Peterson's time frames, 19 August - 5 September 1974, primarily through the use of available transient ship data. Another criterion for choosing this time period was that it coincides with the fog research cruise conducted by the Naval Postgraduate School in conjunction with Calspan Corporation (Mack et al, 1975) off the central California coast. One other time frame was selected, 1-4 December 1975. This period was chosen because of the unique conditions that existed. The fog development during these four days was not typical of the winter (low fog season) but more like fog cases during the summer (high fog season).

The area of investigation was from the North American coast out to 130° west longitude and from 30°-50° north latitude. Based on the advice and experience of several professors at the Naval Postgraduate School

(NPS), Monterey, California, the size of the area was determined so it would probably include all continental influences on the fog formation processes at sea off the western coast of the United States. For the period of 19 August - 5 September 1974, all the marine synoptic reports of transient ships within this area were provided, via Dr. Renard, NPS, Department of Meteorology, by the Naval Weather Service Detachment (NWSD), Asheville, North Carolina. These data, stored on magnetic tape by months only, were not in chronological order of synoptic reporting period. Since there were so few reports, only 1262 for the 18-day period (about 70 per day), each report in synoptic code was reproduced on an IBM-360 data card and re-arranged manually into chronological order, after which a computer print-out was made. For the period of 1-4 December 1975, the transient ship synoptic reports were provided by the Climatology Department, Fleet Numerical Weather Central (FNWC), Monterey, California. Data from NWSD was not used for this period because of a three- to four-month time requirement to collect all marine synoptic reports on their master files. FNWC provided 165 reports for these four days, about 40 per day. Their data were received in a computer printout and were in chronological order. It is not understood why there were about one half as many reports per day during the 1-4 December time period. Perhaps it is an indication that NWSD has the capability of collecting a greater number of marine ship reports than does FNWC.

Other sources of data were used primarily as support for the transient ship observations. They included daily NOAA II visual satellite photographs, synoptic surface analysis maps, and National Marine Fisheries Service (NMFS) 15-day sea surface temperature patterns, all provided by the Departments of Meteorology or Oceanography, NPS.

B. DATA EVALUATION

Marine fog off the western coast of the United States forms in response to the interaction of the existing oceanographic and meteorological conditions. Before one can attempt to describe these conditions over a vast ocean area through the analysis of marine synoptic reports of transient ships, he must be thoroughly aware of all limitations of such observations.

First, there are many inherent difficulties in making accurate shipboard observations. The nature of the ship itself introduces possible errors by its disturbance of the smooth flow of air, its usual irregular motions, and its convective and radiative heat. Even the most sophisticated measuring equipment is subject to error because of these problems. Roll (1965) devotes an entire chapter to these types of problems and to errors in measurements that can be expected. One of the most important weather elements in any fog study is visibility. Unfortunately, visibility in the past has been almost impossible to measure accurately at sea because of the lack of reference points at a known range. Edgerton (1974a,b) discusses in detail the credibility and availability of existing visibility data, and the current state of the art of electro-optical methods for determining visibility at sea. The credibility of visibility reports will be taken up in the section to follow.

Second, it must be understood that the collection of marine synoptic reports of transient ships is conducted on a voluntary, non-profit, cooperative basis, and for the most part, these observations are made by untrained personnel performing a secondary task. The end results are observations of questionable accuracy. Grisham (1973) made the assumption concerning transient ship reports that "it is insisted that such reports are not performed by disinterested individuals performing a chore, but by

responsible individuals answerable to authority"; several findings in this study suggest Grisham's assumption is optimistic. One particular ship during the time period of 19 August - 5 September 1974 submitted 24 synoptic reports, 17 of which reported a sea-surface temperature of 16.3 degrees. The other seven were within 0.3 degrees of this value. Several of these 24 synoptic reports were complete duplications except for the position and day-time group. It is highly unlikely that this ship followed a 16.3 degree isotherm during its 18-day voyage.

Another finding was concerned with inconsistencies in coding of the visibility-weather group section of the synoptic reports. The procedures and requirements for the coding of surface synoptic reports (land and ship) are found in the "Federal Meteorological Handbook No. 2, Synoptic Code" (U. S. Departments of Commerce, Defense, and Transportation, 1969b). These procedures apply internationally to all members of the World Meteorological Organization (WMO). For the time period of 19 August - 5 September 1974, 114 of the 318 ship reports indicating fog, violated WMO procedures. For the time period of 1-4 December 1975, 29 of 42 fog cases were in violation. For a detailed description of these violations see Table I.

A third limitation is that although each report contains many valuable parameters, some key ones are not always reported. The dewpoint temperature was reported so infrequently that it could not be used in this study. While the omission of parameters in the report may be intentional, this might also result from transmission or coding error.

A fourth limitation of the transient ship report is that it provides no upper air radiosonde observations (Raobs). This is unfortunate because Raob data are critical to any synoptic study of marine fog.

Fifth, time series analysis is not possible, obviously because a transient ship does not maintain a fixed position.

The final limitation is that these reports are few in number. The area of investigation in this study consists of approximately 830,000 square miles of ocean. On an average day in the summer 1974 period, about 70 synoptic reports are made within this area, or roughly one report for every 12,000 square miles. Naturally, the reports are not evenly distributed but are confined primarily to the shipping lanes along the coast. Even within the areas of more dense distribution, there are not enough data to determine fine details, and thus the existence of small scale local features are almost impossible to establish.

Even with the knowledge of all the previously discussed shortcomings of transient ship reports, one has no other choice but to use them since they represent the only surface data source for such an area of investigation. One should not accept data of this sort without some degree of skepticism. Care must be taken in the establishment of results and conclusions.

C. DATA TREATMENT

In the most general terms, the ultimate goals of analyzing the ship observations in this study are to determine fog location and boundaries, and reasons why the fog was at this location. Naturally before establishing the reasons, the locations must be determined first, which is no easy task in itself. The basic question to be answered first is how to tell the presence and intensity of fog from the ship reports.

Three elements of the ship report relate directly to fog. They are visibility, present weather, and past weather, all part of the visibility-weather group. Table II is an abridged version of the visibility-weather

group codes. When these three elements are used together, they give a good indication of both fog occurrence and fog duration in the period represented by the report. Approximately 95 percent of the ship reports used in this study were the six-hourly or primary synoptic reports taken at 0000, 0600, 1200, and 1800 GMT. The others were the intermediate synoptic or the three-hourly reports taken at 0300, 0900, 1500, and 2100 GMT. Since the three elements of the visibility-weather group represent actually six hours (the three-hourly intermediate reports were not used) of weather information and not just the conditions at the time of observation, a method for plotting fog location had to be used to take advantage of the full amount of coverage provided by the reports. Willms (1975), devised a scheme, called the SSR-75 program, which was based on previous work by Renard et al (1975). His program determines a fog duration, in hours, from various combinations of visibility, present weather, and past weather values. Willms' duration values are based on actual ship logs which marked the beginning and ending times of fog. Table III illustrates the possible combinations each with an assigned duration value. The ship report with a duration value other than zero is classified as a "fogger"; any other is classified as a "nonfogger". Willms' SSR-75 program is a climatological method for deriving marine fog frequencies over the ocean area from marine synoptic reports. His program was not designed to print-out each report with an assigned duration as would be needed in the approach used in this study. Perhaps a modification to his program could have been made, but since there were only 1427 ship reports in both time periods, the data were manually examined to determine which reports were foggers and a Willms' duration value was assigned accordingly. Out of the total 1427 reports, 360 were foggers. Then each nonfogger and fogger (with

the fogger's duration value) was manually plotted for each day and also for each synoptic reporting period.

An alternative method was examined also. Since fog causes a restriction in visibility to less than 1000 meters, it was thought that fog could be located by plotting visibility (less than 1000 meters) alone. Had this been done, there would have been only 88 fog cases out of 1427 reports. Another possibility was plotting fog cases by present weather code alone. According to the "Federal Meteorological Handbook, No. 2, Synoptic Code," there are 14 present weather codes (10, 11, 12, 28, 40-49) to identify the presence of fog. Table IV gives a brief description of these codes and the visibility requirements that must be met by each. It is important to note that each present weather code has a self-implied visibility requirement. All of the codes except one require the visibility to be less than 1000 meters (5/8 mile). Code 10 is the only present weather code that can be used if visibility is greater than 1000 meters. The use of code 10 implies the visibility is between 1-10 kilometers (5/8 - 6 miles). Thus the use of codes 11, 12, 28, 40-49 would indicate the existence of true fog (visibility less than 1000 meters). Code 10 implies light fog (5/8 - 6 miles). Out of the total 1427 reports, 211 of them had present weather codes (11, 12, 40-49) that imply a visibility of less than 1000 meters at the time of the observation. (Code 28 was not included in this number since its 1000-meter visibility restriction does not occur at the time of observation, but within one hour prior to the observation.) Why are there 211 fog cases using present weather codes alone, and only 88 by using just the reported visibility? Both methods should give equal numbers of fog cases, providing that no other atmospheric phenomenon such as rain or dust was restricting visibility; if other visibility restrictions

occurred, the visibility method would have given a higher number of fog cases. Clearly something is wrong. The problem arises from many ships reporting a present weather code and a visibility code that don't imply the same existing visibility. For example, if a ship reports a visibility of 96 (4-9.99 kilometers) and a present weather code of 44 (implying a visibility of less than 1 kilometer), which one is correct? There is no way to tell for certain. The only definite fact is that the ships' observers are not knowledgeable of the proper coding procedures. Table I gives a complete listing of all the coding inconsistencies which occurred in ship observations during the times of this study. The inconsistencies are divided into five distinct types. Types A, B, C and D are directly related to a specific present weather code(s); type E is the result of no adequate present weather code to describe the restriction to a reported visibility of less than 1000 meters. Type A inconsistency, which had the greatest number, is associated with present weather codes 40-49. In order to use codes 40-49 accurately, a visibility of less than 1000 meters also must be reported. For the 1974 time period, codes 40-49 were reported 167 times with 82 or 49% of them reported with visibilities greater than 1000 meters, some as high as 20 kilometers. For the 1975 time period, 89% had inconsistent visibilities. (See Table I for a description of the other types of inconsistencies.)

Although the inconsistencies still exist even when using Willms' duration scheme, his method definitely gives the best indications of the occurrence of fog since all three elements of the visibility-weather group are used, and since the duration values were checked against actual ship logs. Fog intensity usually is measured by the visibility. Considering the inconsistencies in reported coding of the visibility-weather group elements, plus

the fact that visibility is so difficult to measure accurately at sea, it was concluded that the Willms' duration value, although it was not designed for this purpose, gives a better measure of intensity than does visibility alone. Once the foggers, nonfoggers, and duration values were plotted, fog boundaries were drawn on the basis of duration value contours, fogger/nonfogger distribution, and the satellite photographs (which could be used to indicate boundaries of nonfogger areas).

With the fog locations established, it was then possible to investigate the reasons why the fog was there. Other important elements of the synoptic ship report were analyzed, namely air temperature (T_a), dewpoint temperature (T_d), and sea-surface temperature (T_w). Several charts using these elements were formed. First of all, daily sea surface temperature charts were made. With only about 70 reports per day for the first time period and about 40 per day for the second, detailed accuracy of such charts undoubtedly is lacking. NMFS 15-day sea surface temperature charts were used as a guideline.

The relations of dewpoint temperature to air temperature and to sea surface temperature are critical for fog formation and dissipation processes. Unfortunately, since the dewpoint temperature was omitted approximately 50 percent of the time, attempt to establish any (T_a - T_d) or (T_d - T_w) relationships proved futile. A defining relation between air temperature and sea surface temperature difference (T_a - T_w) and fog occurrence was also attempted. Values of (T_a - T_w) were plotted and contoured. Once again, scarcity of data hampered finding any detailed relationship, especially since no climatological data for this difference were available for guidelines in this ocean region.

One of the final products was trajectories illustrating the prior air mass history of air parcels from the various locations that reported fog occurrence. The trajectories were constructed in the following manner. Surface wind speed and direction were calculated from NWS six-hourly surface analysis maps. Air parcels from the various locations of fog were projected back (in time and space) along the isobars, assuming geostrophic flow, for at least 36 hours or until the parcel was well over land. Corresponding sea surface isotherms were sketched in under the trajectories so that the effect of sea surface temperature on the history of the air parcel could be studied.

IV. RESULTS

A. FOG LOCATION AND BOUNDARIES

As previously discussed in Chapter IV, Section C, of this study, determining the fog location and boundaries was not a simple task. Once each report was classified as a fogger/nonfogger, it was plotted manually along with its assigned Willms' duration value on a daily and primary-synoptic-reporting-period basis. Also plotted was the fog or no-fog condition at each of the nine coastal stations studied by Peterson (1975). Figure 1 gives the position of the nine coastal observation sites, and figures 2 and 3 are a plot of the hourly visibility and cloudiness values at each of the sites. Obviously a Willms' duration value could not be assigned to Peterson's coastal data. Therefore, it was decided to plot his conditions of "heavy fog" and "light fog" as foggers and all others as nonfoggers. Figure 2 gives his definition of each category. [Note that figures 2 and 3 are plotted in local time vice Greenwich mean (Z) time.]

Positive locations of fog/no fog are determined therefore by the foggers/nonfoggers. The fog boundaries, though, are not as simple to determine. They were inferred from the fogger/nonfogger distribution, with more dense concentrations giving more accurate boundaries. Duration-value contours also were used as a guideline for the determination of the fog boundaries. The NOAA II daily visual satellite photographs were used as another means to help indicate the boundaries, especially in the no fog or clear areas. Clear areas on the satellite photographs should correspond directly to the same conditions on the fog location charts.

Although the satellite photographs could not by themselves be used to determine whether or not fog was present under areas of obvious cloud cover, if there were ships under the cloud cover that reported fog, then fog presence could be extrapolated spacially under the cloud cover. Naturally, the greater the number of foggers under a cloud cover, the greater the accuracy in assuming the whole area to be fog. The limitation of the satellite photograph is that it is an instantaneous picture of the atmospheric conditions for only one specific time in each day. The fog boundaries are naturally in a state of dynamic change throughout the day. Even so, the once daily NOAA II visual satellite photographs were used as a guideline for all four primary synoptic time period fog location charts. Since all the photographs were taken at 1800Z plus or minus one hour, the most accurate representation of the true surface conditions should be found in the 1800Z fog location charts. The same photograph was used as a guideline for the 1200Z fog location chart, while the previous day's satellite photograph was used for the 0000Z chart; thus a six-hour time differential existed between the 0000Z and 1200Z fog location chart and their corresponding satellite photograph. The 0600 chart represents conditions 12 hours after one photograph and 12 hours prior to the next, or it corresponds to a transition period between two consecutive photographs.

In a section to follow, the fog location charts for each day are presented and discussed; the location of each fogger/nonfogger observation is indicated. Because of space limitations, the four charts for each day were photo-reduced so that they could be represented in a single figure (see figures 4 through 25). In doing so, the duration value for each fogger was excluded and only the duration contours were plotted. Appendix A presents all the foggers in tabulated form giving location, Willms'

duration value, and the visibility-weather group reported codes. None of the satellite photographs used in this study are included as figures because of their poor reproductive qualities. (Figures 11-16 of Peterson, 1975, demonstrate this for the early part of the Aug-Sept period.)

B. SEA SURFACE TEMPERATURE

Sea surface temperature charts were constructed on a daily basis. There were far too few reports to make such charts on a primary synoptic reporting time basis. All the sea surface temperatures from the ship reports were plotted manually on a daily basis, then contoured using the NMFS 15-day sea surface temperature patterns (figures 26 and 27) as guidelines, especially in areas of low reporting density. The primary use of the sea surface temperature patterns was in conjunction with the trajectories analysis where the effect of surface heating and cooling on air parcels was studied. The sea surface temperature charts are presented in figures 28-44.

C. AIR TEMPERATURE MINUS SEA SURFACE TEMPERATURE (T_a - T_w)

Values of (T_a - T_w) were plotted and contoured for selected days of both time periods. A chart for every day was not made because of the questionable value and accuracy of this product on those days. For the charts that were constructed, 24 hours of data were used so that enough data points would be present for an attempt at establishing a defining relationship. The shortcoming of plotting all data points over one day's time, instead for only one specific time period, is that the temperatures are changing throughout the day. Sea surface temperature changes little, but air temperature can fluctuate over several degrees during a 24-hour period. Even by plotting all the reports in one day, there were still not enough data points for a highly detailed product. No defining

relationship was found between the value of $(T_a - T_w)$ and the occurrence of fog; that is, both foggers and nonfoggers were associated with a wide range of value for $(T_a - T_w)$. Although not exact, the high positive values of $(T_a - T_w)$ many times were associated with large clear areas along the coast as shown by the satellite photographs; this is consistent with the conjecture that such areas represent the flow of a warm, dry air mass off the continent. This flow, according to existing theory, marks an initial condition for fog development. For this reason, $(T_a - T_w)$ charts were made for only those days which had a large tongue of clear air extending over the coastal oceanic region as viewed from their satellite photographs. These charts are presented in figures 45-52.

D. SURFACE TRAJECTORIES

Surface trajectories are presented in figures 53-62. They illustrate the prior air mass history of air parcels from the various locations that reported fog occurrence. With the sea surface isotherms sketched in under the trajectories, it was possible to note the effect of sea surface temperature on the history of the air parcel. The shortcoming of these charts is that they were constructed assuming geostrophic flow between isobars, thus neglecting friction effects and daily sea/land breeze effects. They do give a good general description of pressure gradients and wind direction and speed values, along with the effect of warming and cooling of the air parcels from below by the water.

E. OBSERVED SEQUENCES

In this section, fog development sequences are discussed for each day by an examination of all the accumulated data-fog location charts,

(figures 4-25) sea surface temperature patterns (figures 26-44), $(T_a - T_w)$ charts (figures 45-52), surface trajectories (figures 53-62), NOAA II daily visual satellite photographs, NWF Synoptic Surface Analyses, and observations from Peterson's (1975) nine coastal sites (figures 1-3).

1. <u>19 August 1974</u>

Figure 4 gives a representation of the fog conditions on 19 August 1974. None of the ship reports indicated any fog occurrence. One coastal station, NAS North Island, reported light fog at 1200Z, but it was dissipated by 1800Z. The surface analyses for the 19th showed the eastern North Pacific subtropical high just off the coast of Washington and the isobars oriented north-south along the coast. According to Peterson (1975), the 19th exhibits the conditions for his Stage I. No satellite photo was available for this day.

2. <u>20 August 1974</u>

Figure 5 gives a representation of the fog conditions on 20 August 1974. One ship reported fog at 0000Z off the coast of Oregon. This must have been just a small local patch of fog for the other ships in the area reported none. There were no foggers at 0600Z. The 1200Z (0500 local) chart shows coastal fog at Monterey and Pt. Mugu, but by 1800Z the fog was dissipated by late morning heating effects. Perhaps the fog was continuous from Monterey to Pt. Mugu, but no supporting data confirmed this. There was only one fogger at 1800Z which was located off the northern coast of Washington, again, representing only a small local patch.

The satellite photograph shows a huge tongue of clear air off the coast from 45°-33°N out to 127°W. This represents the flow of warm, dry air off the continent and along the isobars which were oriented almost parallel to the coast. This is also supported by the $(T_a - T_w)$ chart,

figure 45, which shows large positive values for $(T_a - T_w)$ within this clear area. This offshore flow was brought about by the eastern North Pacific subtropical high pushing well inland over Oregon and the strengthening of the thermal trough over California. The satellite photograph also shows an area of stratus off the southern California coast. The 20th marks the transition to Peterson's Stage II.

3. <u>21 August 1974</u>

Figure 6 gives a representation of the fog conditions for 21 August 1974. There was no reported fog at 0000Z and 0600Z, but the 1200Z chart shows almost the same fog conditions as existed at 1200Z on the 20th except the fog extends further north up to Pillar Point. Late morning heating did not dissipate the coastal fog in the Monterey, San Francisco area, as it did on the 20th, but instead, the fog extended further north up to Bodega Bay as seen on the 1800Z chart. The fog was dissipated at Pt. Mugu by 1800Z. There were three other foggers on the 1800Z chart, probably associated with the stationary front situated in the northwest section of the study area. These foggers might represent the beginning of fog development on the western edge of the tongue of warm air. The satellite photograph did not extend far enough north for any supporting basis for these foggers.

The satellite photographs show the area of the tongue of warm, dry air to be slightly larger, and the stratus off the southern California coast developing into a wedge moving northward along the coast. The $(T_a - T_w)$ chart, figure 46, illustrates that warm air is within the clear area. This chart also shows large positive values of $(T_a - T_w)$ under the stratus wedge, a condition which may give an indication of a future fog formation area.

4. <u>22 August 1974</u>

Figure 7 illustrates the fog conditions for the 22nd. The 0000Z (1700 L, 21 August) chart illustrates that all the coastal and offshore fog was dissipated by afternoon heating, indicating the marine layer under the inversion has not developed to a thickness great enough to maintain the presence of fog during afternoon heating. But by 0600Z, with early evening cooling the coastal fog is seen to return from Monterey southward to Pt. Mugu. By 1200Z the fog has developed farther north up to Pillar Point and farther out to sea. By 1800Z the fog has been dissipated at all the coastal sites except Santa Cruz and Pillar Point but continues to be maintained off the coast, which indicates that the fog layer has become deep enough to be maintained over the sea both day and night, but not thick enough to be maintained over land during afternoon heating. This supports both Leipper's (1948) model, Stage IV, and Peterson's (1975) model, Stage III. According to these two models, low to negative values of $(T_a - T_w)$ should be found at the fog areas. Figure 47 does in fact support this expected result. The wedge of fog off Point Conception on the 1800 chart coincides with the area of large positive values of $(T_a - T_w)$ found the day before on figure 46.

The satellite photograph shows that the tongue of clear, warm, dry air is still present. This band of clear air is over a hundred miles wide and extends from about 50°N to 32°N with its outer edge paralleling the 125°W line of longitude. Figure 47 indicates that high values of $(T_a - T_w)$ are present within this area and low to negative values on either side. The presence of fog along the eastern edge of this band of clear air has already been established. Figure 7 also indicates that fog has developed along the western edge. Indications of fog development in this area began

on the 1800Z chart of 21 August (Figure 6) with a few foggers in the northern section. The 0000Z chart of 22 August (figure 7) shows foggers occurring farther south, suggesting that the band may be continuous as illustrated by the satellite photograph. The fog on the western edge was not dissipated, as was the coastal fog by afternoon heating, suggesting that the growth of the fog layer on the outer edge may occur more rapidly. No fog boundaries on the western edge were drawn on the 1200Z chart only because there were no ship reports in that locality for support; the probability that fog was there is high. The 1800Z chart shows fog at the western edge only in the southern portion; fog probably extended much farther north as indicated by the satellite photograph which shows a continuous band of fog/stratus along the entire western edge of the clear band of air.

Figure 53 shows two surface trajectories, one from each of the two fog areas as seen on the 1800Z chart of figure 7. The trajectories illustrate the manner in which the warm dry air flows initially seaward off northern California along the southern portion of the North Pacific subtropic high and then is deflected to the south along the western edge of the low pressure trough which is centered over central and southern California. Although both trajectories initially pass over increasingly warmer water the air parcels are still being cooled from below because of the initial high temperature of the air as seen in the $(T_a - T_w)$ chart, figure 47.

5. <u>23 August 1974</u>

Figure 8 gives a representation of the fog conditions for the 23rd. The 0000Z (1700L) chart shows that fog continues to persist off the coast during the late afternoon while all coastal fog has been dissipated. Fog along the western edge also has been maintained. Several small local patches

of fog have begun to develop along the coast of northern California and Washington. By 0600Z the fog has moved over the coast from Pt. Mugu northward to Monterey with clear conditions reported in the San Francisco area. Fog off the coast has moved as far north as Cape Mendocino. The band of fog that occurred along 125°W on the 0000Z chart probably has persisted through 0600Z, especially since there is evidence of its continued existence on the 1200Z chart. Similar conditions occurred through 1200Z but coastal fog has developed at Bodega Bay and NAS North Island. By 1800Z the coastal fog has moved off shore in the southern California area while the offshore fog has moved over the coast in central California.

The satellite photograph for the 23rd no longer indicates the presence of the tongue of clear air that had been present in previous days. Instead, the entire study area is covered with a patchy fog/stratus system, making it more difficult to use this satellite photograph to establish fog boundaries. The presence of the band of fog along 125°W which existed previously cannot be established because of the patchiness indicated by the satellite photograph and the lack of ship reports in the area during this reporting period and the next several to follow.

The $(T_a - T_w)$ chart, figure 48, indicates that the central area of positive $(T_a - T_w)$ values centered around 37N, 125W has decreased substantially in magnitude from the previous day, figure 47, which is consistent with the lack of a tongue of clear air on the satellite photograph.

Figure 54 shows a trajectory ending at 1800Z on the 23rd. The trajectory initially follows the 14° isotherm then crosses it over to colder water, thus intensifying the cooling from below.

6. 24 August 1974

Figure 9 represents the fog conditions for the 24th. The 0000Z chart shows that the coastal fog is again dissipated by the afternoon heating while the fog offshore is maintained. By 0600Z with early evening cooling, the fog moves over the coast again from Pt. Mugu northward up to Bodega Bay, and by 1200Z the coastal and offshore fog bank has moved north of Cape Mendocino and southward to the San Diego area. As with the 23rd, by 1800Z the coastal fog along the southern California coast has moved offshore while fog along the central California coast has been maintained. The 1800Z chart shows that the growth of the coast fog bank has moved northward along northern California, Oregon and Washington. The satellite photograph indicates that this coastal and offshore fog bank extends about 50-70 miles offshore after which patchy and clear areas predominate.

The satellite photograph again shows no tongue of clear air. The entire study area is covered with a fog/stratus system with intense covering in the southern sections and patchy covering in the central and northern sections. In the southern areas, west of 125°W, where earlier on the 21st and 22nd an intense fog bank was developed, there was no evidence on the 23rd and 24th of its existence. There were several nonfoggers in this area on the 24th suggesting that the fog layer grew to a sufficient thickness so that it was lifted above the surface, marking the end of the fog sequence and the beginning of the stratus regime. If this in fact was the case, it marks the second indication of a more rapid fog development on the western (outer) edge of the initial clear band of warm, dry air, compared to fog development along the eastern, near-coastal edge.

7. <u>25 August 1974</u>

Figure 10 gives a representation of the fog conditions on the 25th. The 0000Z chart indicates the fog layer finally has grown to a thickness such that it is not dissipated by late afternoon heating over the coastal areas from Monterey northward to Bodega Bay. The fog conditions are almost exactly the same as they were six hours earlier on 1800Z, 24 August. The 0600Z chart shows persisting conditions except that the Monterey area reported overcast conditions indicating that the inversion height was raised above 400 meters bringing the fog off the surface. The 1200Z and 1800Z charts indicate the persistence of coastal and offshore fog along the northern California, Oregon and Washington coasts and overcast conditions in the Monterey and San Francisco areas. Uncertain conditions exist off southern California, for at 1200Z Pt. Mugu reported fog, NAS North Island reported haze indicating that the fog regime was still present; while at 1800Z, they both reported haze indicating that the fog was dissipated due to early morning heating. Thus fog probably was present offshore of Pt. Mugu although there were no ship reports to support this theory.

Figure 55 shows a surface trajectory which ended at 1500Z 25 August. Although the air parcel passed over progressively warmer water, the water was sufficiently cold to condition the air for fog formation and development.

8. <u>26 August 1974</u>

Figure 11 gives a representation of the fog conditions for the 26th. The 0000Z chart shows a continuation of the same conditions as on the 25th. Fog persists for the whole day over cold water off the coasts of northern California, Oregon and Washington. The conditions at the central California coastal sites alternate between reported overcast during the day and fog at

night. The foggers west of 125°W appear to be associated with scattered areas of fog which is consistent with the patchiness observed on the satellite photograph.

There now appears to be four distinct zones of fog occurrence. The first zone is a band of fog about 50-100 miles wide off the coast of northern California, Oregon and Washington. This band of fog is thick enough that it persists both day and night and is associated with the cold upwelled water along the coast. Most of the foggers occur between the 16° isotherm (oriented north-south) and the coast. The band of fog has persisted since 1800Z, 24 August and is easily discernible by the fogger/non-fogger distribution and the satellite photographs which show the coastal mountain ranges acting as barriers to any shoreward movement of the fog bank. This fact is noteworthy for in the later stages of this sequence, around 29 August, when the stratus regime has begun, the coastline will no longer be visible.

The second zone, which occurs off the coast of central California, is a southern extension of the first zone, but with a few differences. Within this zone the stratus regime is predominating with coastal stations and offshore ships experiencing overcast conditions (no fog) during the day (see the 0000Z chart of figure 11) and fog at night (see the 1200Z chart of figure 11).

The third zone is associated with the scattered areas of fog occurring west of 125°W. This zone may represent the final stages of a fog/stratus regime with fog, overcast, and clear conditions existing all at the same time.

The fourth zone occurs off the coast of southern California. The conditions within this zone are difficult to determine because of lack of

ship reports, but appear to be similar to those conditions off the central California coast.

9. <u>27 August 1974</u>

Figure 12 gives a representation of the fog conditions for the 27th. Conditions are similar to those on the 26th with the four zones of fog occurrence still persisting.

10. <u>28 August 1974</u>

Figure 13 gives a representation of the fog conditions for the 28th. The four zones of fog occurrence continue to persist up until 1800Z. The 1800Z chart indicates that the fog/stratus regime has moved farther northward up to southern Oregon. Two facts support this finding. First is the distribution of nonfoggers off northern California, and second, is the satellite photograph which shows stratus inland from the coast. The coastal mountains would prevent the inland movement of fog in this area, but are no barrier to higher stratus.

Figure 56 shows two surface trajectories with an ending time of 1800Z on the 28th. Once again the trajectories show air parcels essentially paralleling the isotherms but passing over progressively warmer water. The northernmost trajectory more closely follows the 16° isotherm and ends in the area of thick fog off the Oregon coast, whereas the southern trajectory, after 1500Z on the 26th, moves closer along the 18° isotherm, eventually crosses it early on the 28th, and ends in the area of patchy fog conditions west of 125°W. This fact indicates the patchy fog conditions may be associated with movement of air parcels over water several degrees warmer than 16°C.

11. <u>29 August 1974</u>

Figure 14 shows persisting fog conditions for the 29th. Because of the lack of ship reports off the Oregon-Washington coast on the 1200Z chart, the presence of fog could not be established in this area, although the probability of its existence there is great.

Figure 57 shows two surface trajectories with an ending time of 1800Z on the 29th. The southernmost trajectory shows that the air parcel initially passes over increasingly warmer water, but completes its path by passing over decreasing sea surface temperatures. The final cooling was probably responsible for the small patch of fog in this area. The northern trajectory basically parallels the 14° isotherm. The temperature was cold enough to condition the air parcel for fog formation.

12. <u>30 August 1974</u>

Figure 15 gives a representation of the fog conditions on the 30th. The band of fog off the Oregon-Washington coast persists but in a less continuous pattern. The California coast and offshore areas are dominated by overcast conditions as shown by the satellite photograph and reported by the coastal sites. Fog occurred at two coastal stations at 1200Z probably due to late night radiation, but it was dissipated by early morning heating.

13. <u>31 August 1974</u>

Figure 16 gives a representation of the fog conditions on the 31st. The fog off the Oregon-Washington coast occurs only in small patches at 0000Z and 0600Z. By 1200Z all the fog has disappeared indicating that this area has reached the stratus regime. As on the 30th, fog, presumed to result from radiation, formed during the night at almost all the coastal stations. By 1800Z all the fog has been dissipated and none was reported

anywhere in the study area, except for only one fogger off Vancouver Island. The entire area is dominated by overcast as shown by the satellite photograph.

The surface trajectory, figure 58, parallels the coast with the associated air parcel experiencing alternating periods of warming and cooling as it passes over the cold coastal water. Although the air parcel spent several days over the cold coastal water, the end result was only a small patch of fog indicating a requirement of more than just cooling from below for a development of a thick fog bank in this area.

14. <u>1-2 September 1974</u>

The fog conditions for the 1st and 2nd are presented in figures 17 and 18, respectively. The satellite photograph indicates that the 1st is dominated by overcast conditions with most of the coastal sites experiencing radiation fog at 1200Z as on the previous days. The 2nd is characterized by the same conditions but with a fog bank returning to offshore Oregon and Washington.

15. <u>3 September 1974</u>

Figure 19 presents the fog conditions for the 3rd. The 0000Z and 0600Z charts indicate that the size of the band of fog off Oregon and Washington has been reduced to patchy conditions. The 1200Z chart again shows most of the coastal sites experiencing fog, presumed due to late night radiation. The 1800Z chart indicates the coastal fog has been dissipated and several patches of fog occur off the central California coast. The satellite photograph indicates a large change in the overall offshore conditions by 1800Z. The study area is no longer dominated by overcast conditions but now is characterized by generally clear conditions with scattered areas of patchy cloud cover.

16. 4-5 September 1974

The fog conditions for the 4th and 5th are presented in figures 20 and 21, respectively. Generally, clear conditions prevail up until 1200Z on the 4th. From 1200Z on the 4th, through the 5th, the central California coastal sites are dominated the continual presence of fog indicating that area has returned to a fog regime. The presence of nonfoggers off the central California coast throughout the 4th and 5th indicate that the fog is primarily confined to only the coastal area. Overcast conditions predominate in the area off southern California as shown by the satellite photograph, with a few isolated foggers offshore.

17. 1-4 December 1975

The second period of this study was from 1-4 December 1975. Detail in the observed daily sequence of fog development is much less than during the first period for two reasons. One is that number of ship observations is about one half that reported in the earlier season, approximately 40 per day vice 70 per day. The second reason is the incomplete record of coastal data. Coastal data was to be provided via a concurrent study, which unfortunately was never completed.

The synoptic conditions for this winter time period are extremely different from summer time conditions. The sea surface temperatures, in general, are colder with isotherms oriented east-west except along central California where they parallel the coast. Figures 41-44 present the sea surface temperature patterns for these four days. The surface pressure patterns vary greatly, also. The isobars north of Cape Mendocino are oriented east-west with decreasing pressures to the north. Two large high pressure systems are present south of Cape Mendocino. One is centered

several hundreds of miles off the coast and the other is centered over southwestern United States, resulting in the isobars paralleling the coast south of Cape Mendocino.

In general the area north of Cape Mendocino was dominated by a permanent overcast throughout these four days as indicated by the satellite photographs.

The satellite photograph for the 1st shows a huge tongue of clear air off central and southern California very similar (but smaller) to the early fog development conditions for August 1974. This area of clear air also appears to be warm relative to the sea surface as seen by the abundance of positive $(T_a - T_w)$ values on figure 49. The air is also dry because of the subsiding air flow associated with the high pressure system centered over the southwestern United States. The surface trajectories in figure 59 show two contrasting paths of air flow associated with the orientation of the isobars discussed above. The southern trajectory illustrates the manner in which the warm dry air originating in southern California initially moves in a northwesterly direction and then is deflected southward over the cold water along the central California coast, resulting in the tongue of clear air. The northern trajectory indicates the source of the air parcel is from a colder latitude resulting in lower $(T_a - T_w)$ values as seen by figure 49.

As shown in figure 22, there are too few surface reports to establish accurate fog boundaries. There are several foggers north of 40°N indicating that some portion of the overcast shown by the satellite photograph may also represent fog development in this area. The 1800Z chart of 1 December does show the beginning of fog development on the outer edge of the warm clear tongue of air.

Figure 23 shows a continuation of fog growth along the outer edge of the clear air throughout the 2nd. The boundaries are supported by the

satellite photograph. Several foggers are present north of Cape Mendocino, but because of the heavy overcast in this area, boundaries could not be drawn. Figure 60 shows the paths of two surface trajectories for the 2nd. The origins of both are not as far south as the one on the 1st; thus the air temperatures along the trajectories are lower. This, along with the fact that the path of the air parcels is over increasingly warmer water, results in low to negative values of $(T_a - T_w)$ as shown by figure 50. Larger positive values of $(T_a - T_w)$ are present within the band of clear air off central and southern California.

The 3rd is dominated by a growth of fog on the inside of the band of clear air resulting in a continuous wedge of fog from Cape Mendocino southward to off southern California as shown by figure 24. Low to negative values of $(T_a - T_w)$ occur under this wedge of fog, illustrated by figure 51.

A representation of the fog conditions for the 4th is presented in figure 25. The 4th is marked by a drastic reduction of fog with several nonfoggers offshore and generally overcast conditions reported at the coastal stations. In this case, the fog regime was very short-lived with a transition to the stratus regime after only two days, a condition not untypical of winter time conditions for this area.

V. CONCLUSIONS

Although there are many inherent difficulties in taking observations at sea, the synoptic ship reports are practically the only source of such observations and must be used despite the many inconsistencies found therein. Therefore, any scheme using multiple elements of the ship report to determine the presence of fog is assumed to give a more accurate representation of the actual existing conditions than would a scheme using only one. Through the use of Willms' fogger/nonfogger scheme, which uses three elements of the synoptic ship report, a good general description of the offshore marine fog conditions was obtained for the periods studied. Naturally fine detail was lacking due mainly to the large size of the study area and the small number of ship reports. It was not the intent of this study to determine small scale local conditions of marine fog development; the primary objective was to establish large scale descriptive conditions of offshore fog development and to evaluate how these conditions corresponded with a completed fog study based on coastal observations (Peterson, 1975). The results obtained within this study did relate significantly to Peterson's work.

Because of the nature of the data, the construction of a large number of products was not possible, but each of the four products (fog location charts, sea surface temperature charts, $(T_a - T_w)$ charts, and the surface air parcel trajectories) that were formed from the transient ship data did contribute significantly to the final descriptive results. The fog location charts show the areas of fog development and growth, and how they vary

throughout the day. These areas were determined primarily by fogger/non-fogger distribution and satellite photography. The Willms' duration values, although very useful in a climatological type study, did not contribute greatly to these charts. However, in areas of heavy concentration of ship reports, the contours of the duration values did appear to parallel the fog boundaries.

Because of the day-to-day consistency of the sea surface temperature charts and their similarity to the 15-day patterns of the NMFS sea temperatures, it can be concluded that the distribution of the ship reports, even despite the small number, was such that reasonably accurate charts of sea surface temperature can be constructed on a daily basis.

Although there was not a direct correlation between values of $(T_a - T_w)$ and fog occurrence (fog occurred over a wide range of $(T_a - T_w)$ values), there did appear to be a correlation between areas of high positive value of $(T_a - T_w)$ on one day being followed by areas of fog one or several days later. High positive values of $(T_a - T_w)$ also were very indicative of areas of offshore flow of warm, dry air (supported by trajectory analysis) which were seen on the satellite photographs as tongues or bands of clear air.

The observed sequences found in this study did support existing models of fog formation processes along the California coast, namely those of Leipper and Peterson. The sequence for the August-September 1974 period begins with the eastern North Pacific subtropical high pushing inland over northern California, Oregon and Washington causing the surface isobars to lie almost parallel to the California coast, and warm dry air to flow offshore along these isobars. Within the area of offshore flow, air temperatures are in general several degrees warmer than the sea surface temperatures; an inversion is formed at the surface which restricts the vertical movement

of moisture and a thin lower marine layer approaches saturation. With continued cooling of the air mass from below, the marine layer thickens and the inversion rises. Fog first forms over the central and southern coast at night (1200Z) but is dissipated by late morning (1800Z) heating. The marine layer eventually reaches a thickness such that fog is maintained off the central and southern California coasts both day and night and over the coast only during the night. This represents the fog development along the inner edge of the band of warm dry air found just offshore from the coastline. At the same time, a band of fog is developing along the outer edge of the warm air band which is also maintained throughout the day and night. While the inner edge fog development appears to be associated with the cold water along the coast, the outer edge development is not associated with an equivalent band of cold water; this indicates that once the air mass is gradually conditioned for fog development, fog can form over both warm and cold water. This fact is also supported by the trajectory analyses which show that fog may develop even though the air parcels pass over increasingly warmer water.

The above sequence is maintained for several days until eventually the fog layer reaches a thickness such that fog may be maintained over the central and southern California coasts during the day also. By the time this happens the tongue of clear air is no longer visible on the satellite photographs; the band of fog that was associated with the outer edge has reached a stratus regime, suggesting that the fog developmental sequence is more rapid along the outer edge area. This period is characterized by the presence of a fog/stratus wedge off the central California coast.

After a day or so, the fog wedge grows northward and eventually a band of coastal fog, 50-100 miles wide, is developed along the northern California,

Oregon, and Washington coast.

This fog band is maintained continuously for approximately three to four days whereas the wedge along the central and southern California coast reaches the stratus regime after about a day. Eventually all areas are dominated by a stratus regime, during which many of the coast sites experience fog during the night (1200Z) and offshore areas experience clear, patchy fog, or overcast conditions during the same time.

The sequence of fog development for the winter period (December, 1975) in several respects is similar to the summer sequence above. The initial conditions are similar in that the surface pressure pattern produces off-shore flow of clear, warm, dry air south of Cape Mendocino. The fog initially develops on the outer edge of the tongue of warm air followed by fog growth a day later on the inner edge; this results in a wedge of fog off the central and southern California coast, which persists for only a day prior to entering a stratus regime. The entire sequence is only about four days in length.

VI. RECOMMENDATIONS

The greatest problem area in the construction of these charts was the large amount of time required to hand plot them. If a computer plotting routine could be developed, greater amounts of data could be processed covering a much larger time span, thus extending results into other seasons and years. If offshore fog/stratus conditions were described for long periods of time, a comparison could be made with coastal conditions with the ultimate objective of correlating the two; that is, offshore conditions could be inferred from the regularly available observations along the coast. As it was, this study could analyze only three weeks of data which was not enough to establish if the sequence of events studied is a common occurrence.

APPENDIX A

FOGGER LOCATION AND DESCRIPTION

Day	Total # of Ship Reports	# of Foggers	VIS less 1000 m	Duration	(VV) Visibility	(ww) Present Weather	(w) Past Weather	Latitude (°N)	Longitude (°W)
19 Aug 1974	59	0							
20 Aug 1974	83	2	0	4.0	94	44	2	44.0	124.7
				4.0	97	40	2	48.4	124.4
21 Aug 1974	74	3	1	3.6	93	43	0	48.5	125.1
				5.1	95	10	4	43.1	128.9
				4.3	97	41	5	46.8	130.0
22 Aug 1974	87	9	3	5.5	90	41	4	38.1	128.0
				3.6	94	45	3	47.0	128.3
				5.5	93	42	4	40.9	127.1
				3.5	97	10	2	34.3	120.2
				5.5	97	41	4	37.3	122.9
				5.5	93	47	4	35.8	125.5
				3.5	96	10	2	35.8	122.1
				3.3	96	28	1	33.4	127.3
				2.6	97	10	0	37.3	122.8
23 Aug 1974	70	26	6	4.0	98	41	2	32.1	128.4
				3.1	--	01	4	32.4	125.4
				3.6	92	41	0	34.7	121.8
				5.1	96	10	4	46.3	124.8
				5.5	94	46	4	46.5	124.8
				4.0	94	43	2	41.3	124.9
				3.0	96	10	5	46.2	124.2
				3.1	98	01	4	45.9	124.5
				3.1	98	03	4	46.2	124.2
				4.0	95	44	2	37.0	123.5
				3.1	--	--	4	38.4	123.6
				5.3	92	28	4	39.8	124.6
				3.5	96	10	2	32.6	126.0
				3.1	98	01	4	35.6	121.5
				3.1	98	02	4	36.3	129.3
				5.1	96	10	4	37.1	122.7
				5.5	94	45	4	38.4	123.0
				3.1	--	--	4	38.4	123.6

Day	Total # of Ship Reports	# of Foggers	VIS less 1000 m	Duration	(VV) Visibility	(ww) Present Weather	(w) Past Weather	Latitude (°N)	Longitude (°W)
23 cont.				5.3	92	28	4	38.8	124.0
				3.0	96	10	5	46.2	124.2
				5.1	96	10	4	37.0	122.7
				5.5	93	45	4	37.0	123.0
				2.6	97	10	0	38.3	123.6
				5.5	94	45	4	38.4	123.7
				3.6	92	46	1	43.8	124.6
24 Aug 1974	63	29	7	3.5	95	10	2	37.1	122.4
				5.3	97	28	4	37.4	124.0
				3.5	95	10	2	38.3	123.5
				5.5	92	43	4	38.1	123.2
				4.0	97	41	2	38.9	128.4
				5.5	96	40	4	41.2	124.9
				5.3	97	28	4	37.5	124.2
				5.3	94	28	4	48.3	126.0
				3.1	96	55	4	44.6	128.6
				3.5	95	10	2	38.2	123.6
				4.0	96	40	2	39.3	124.4
				5.5	93	45	4	41.5	124.6
				3.5	96	10	2	46.2	124.2
				5.5	93	45	4	44.6	124.3
				4.0	93	41	2	44.8	125.1
				4.0	91	47	2	46.2	124.2
				5.5	95	45	4	37.3	123.5
				3.5	95	10	2	38.1	123.6
				5.3	95	28	4	38.1	123.7
				3.1	--	--	4	48.6	128.2
				5.3	95	28	4	39.6	124.4
				5.5	91	45	4	39.7	124.3
				1.0	94	52	0	39.2	124.2
				4.0	95	42	2	44.0	123.9
				5.5	94	45	4	43.4	127.5
				5.5	91	47	4	43.8	124.6
				5.5	94	45	4	43.9	124.6
				3.1	--	--	4	41.5	124.7
				3.1	--	--	4	46.2	124.2
25 Aug 1974	76	43	10	3.1	98	05	4	33.2	121.7
				3.5	96	10	2	46.2	124.2
				5.3	96	28	4	37.9	126.9
				5.5	90	45	4	38.6	123.5
				3.5	95	10	2	38.2	123.6

Day	Total # of Ship Reports	# of Foggers	VIS less 1000 m	Duration	(VV) Visibility	(ww) Present Weather	(w) Past Weather	Latitude (°N)	Longitude (°W)
25 cont.				5.3	94	28	4	38.9	124.0
				5.5	95	45	4	39.8	124.5
				5.3	97	28	4	48.2	125.1
				4.0	95	44	2	48.9	127.6
				3.1	98	02	4	49.2	129.7
				5.5	91	45	4	43.6	124.7
				5.5	92	47	4	43.8	124.6
				3.5	96	10	2	40.6	125.1
				5.5	94	45	4	41.5	124.7
				3.1	98	01	4	39.3	124.0
				5.5	92	44	4	47.4	127.0
				3.1	97	01	4	41.5	124.8
				5.5	91	45	4	46.2	124.2
				4.3	95	43	5	44.7	128.0
				5.5	93	45	4	38.4	123.5
				4.0	95	43	2	38.2	123.6
				3.1	--	--	4	46.2	124.2
				3.1	96	02	4	40.1	124.5
				5.5	93	41	4	43.6	125.0
				3.5	96	10	2	41.1	124.8
				1.0	94	12	3	41.5	124.5
				5.5	94	45	4	41.5	124.6
				3.1	--	--	4	46.2	124.2
				1.0	98	11	2	32.2	126.2
				5.5	95	45	4	41.5	114.6
				5.5	93	45	4	44.2	124.6
				3.1	98	05	4	44.6	125.0
				5.1	96	10	4	44.9	125.0
				5.5	93	43	4	45.0	124.2
				3.5	96	10	2	37.5	127.1
				5.5	92	45	4	39.5	124.4
				3.1	--	--	4	46.2	124.2
				3.1	99	02	4	47.9	127.6
				5.1	98	10	4	43.8	124.6
				5.3	97	28	4	41.1	124.6
				5.5	94	45	4	41.5	124.7
				3.1	98	01	4	46.2	130.0
				3.1	--	--	4	46.2	124.2
26 Aug 1974	73	42	12	1.0	97	12	2	31.8	127.7
				1.0	97	11	2	31.4	126.5
				1.0	97	11	2	33.6	126.4
				5.5	92	45	4	44.2	124.6

Day	Total # of Ship Reports	# of Foggers	VIS less 1000 m	Duration	(VV) Visibility	(ww) Present Weather	(w) Past Weather	Latitude (°N)	Longitude (°W)
26 cont.				5.5	92	45	4	45.0	124.2
				5.5	94	45	4	37.9	123.5
				5.5	93	45	4	38.3	123.7
				3.5	95	10	2	38.3	123.6
				5.5	92	45	4	39.5	124.4
				5.3	97	28	4	42.0	124.4
				5.5	91	47	4	43.8	124.6
				3.6	93	40	3	41.5	124.6
				1.0	96	11	2	31.0	125.7
				1.0	97	11	2	44.5	126.0
				5.5	93	45	4	45.0	124.2
				5.5	95	43	4	37.5	124.1
				3.5	95	10	2	38.3	123.6
				3.1	--	--	4	42.9	124.8
				5.1	96	10	4	40.2	124.1
				3.1	96	00	4	41.2	124.8
				3.1	--	--	4	46.2	124.2
				3.0	97	11	4	37.9	127.2
				5.5	92	45	4	39.8	124.5
				3.5	95	10	2	39.1	124.3
				3.1	--	--	4	46.2	124.2
				4.0	95	43	2	44.0	123.9
				3.1	--	--	4	43.5	124.3
				5.1	96	10	4	41.5	124.4
				5.5	93	45	4	41.5	124.6
				4.7	92	02	4	46.2	124.2
				4.0	95	43	2	44.3	124.9
				5.5	93	45	4	44.2	124.6
				3.1	--	--	4	44.2	124.2
				5.5	92	43	4	45.0	124.1
				5.3	94	28	4	36.2	127.0
				3.5	97	10	2	38.1	129.8
				5.5	94	45	4	39.8	124.5
				5.5	94	43	4	39.7	124.5
				3.1	98	01	4	46.2	124.2
				5.5	94	47	4	43.8	124.6
				5.5	95	44	4	41.5	124.5
				5.1	98	10	4	35.6	125.6
27 Aug 1974	73	25	6	3.1	98	02	4	35.2	124.3
				5.5	95	40	4	33.8	126.2
				5.5	91	42	4	44.5	124.5
				3.1	97	00	4	45.0	124.1

Day	Total # of Ship Reports	# of Foggers	VIS less 1000 m	Duration	(VV) Visibility	(ww) Present Weather	(w) Past Weather	Latitude (°N)	Longitude (°W)
27 cont.				3.1	97	04	4	36.9	126.9
				5.1	96	10	4	39.8	124.3
				5.5	92	44	4	42.2	124.7
				5.5	93	45	4	40.5	124.9
				3.1	98	01	4	44.2	124.6
				3.1	97	05	4	45.0	124.2
				3.5	96	10	2	37.1	122.5
				5.1	96	10	4	39.9	124.3
				5.5	91	45	4	43.5	124.8
				3.5	96	10	2	41.2	124.8
				4.0	95	43	2	33.7	124.6
				5.1	95	10	4	32.1	128.2
				5.1	96	10	4	44.6	124.7
				5.5	91	45	4	43.5	124.8
				5.1	96	10	4	40.5	125.0
				5.5	91	45	4	44.2	124.8
				5.5	94	45	4	44.2	124.6
				4.3	95	43	5	37.6	112.1
				5.5	97	40	4	40.2	124.3
				5.5	94	43	4	40.5	124.8
28 Aug 1974	66	30	7	5.1	97	10	4	44.2	124.8
				3.1	97	02	4	30.4	116.3
				5.5	95	42	4	37.6	123.0
				5.5	95	45	4	40.0	122.7
				5.5	93	45	4	40.5	124.9
				5.5	94	45	4	41.7	124.8
				3.1	96	05	4	45.0	124.2
				5.5	93	47	4	48.8	126.8
				3.1	96	50	4	37.6	123.1
				3.1	98	02	4	37.0	124.4
				3.6	91	40	1	46.2	124.2
				3.1	97	05	4	33.6	120.3
				3.3	95	28	1	45.9	124.4
				3.1	95	51	4	45.0	124.2
				4.3	94	45	5	37.5	122.9
				5.5	91	45	4	46.2	124.2
				5.5	96	40	4	40.7	124.7
				4.0	95	43	2	43.8	124.7
				5.1	96	10	4	41.2	125.0
				5.5	92	45	4	46.2	124.2
				4.3	97	40	5	31.0	127.9
				3.1	98	20	4	31.0	126.5
				5.5	94	47	4	44.6	124.7

Day	Total # of Ship Reports	# of Foggers	VIS less 1000 m	Duration	(VV) Visibility	(ww) Present Weather	(w) Past Weather	Latitude (°N)	Longitude (°W)
28 cont.				4.0	95	45	2	44.3	124.5
				4.7	93	51	4	45.0	124.2
				4.0	95	45	2	46.2	124.2
				3.1	98	04	4	48.5	125.5
				3.1	95	55	4	43.5	124.5
				5.5	93	45	4	43.7	124.8
				5.5	94	45	4	46.2	124.2
29 Aug 1974	60	30	6	5.5	92	45	4	44.5	124.5
				5.5	94	47	4	44.3	124.9
				5.5	92	45	4	44.1	124.9
				2.6	97	10	1	45.6	124.5
				5.5	93	47	4	45.0	124.2
				5.5	95	43	4	46.2	124.2
				5.5	93	45	4	40.5	124.9
				5.5	96	40	4	40.6	124.7
				3.1	--	--	4	46.2	124.2
				5.1	96	10	4	44.7	124.6
				3.1	95	55	4	45.0	124.1
				5.5	92	45	4	43.9	124.9
				4.0	95	45	2	46.2	124.2
				5.5	96	40	4	40.0	123.5
				3.5	96	10	2	40.0	124.6
				5.5	95	45	4	46.2	124.2
				5.1	96	10	4	35.7	124.7
				5.1	96	10	4	46.2	124.2
				5.1	96	10	4	43.3	125.0
				5.5	94	47	4	46.2	124.2
				3.1	96	05	4	45.0	124.2
				5.5	95	45	4	46.6	124.5
				5.5	95	45	4	46.2	124.2
				3.3	95	28	1	46.2	125.3
				1.0	98	11	2	46.3	126.4
				4.0	95	45	2	47.0	124.6
				4.0	94	43	2	43.2	124.9
				5.5	91	45	4	43.9	124.9
				4.0	94	43	2	41.7	124.9
				5.1	96	10	4	46.2	124.2
30 Aug 1974	78	17	10	5.5	93	45	4	47.6	125.1
				3.1	96	50	4	42.9	125.0
				5.5	92	45	4	43.4	124.9
				5.5	93	45	4	44.0	124.9

Day	Total # of Ship Reports	# of Foggers	VIS less 1000 m	Duration	(VV) Visibility	(ww) Present Weather	(w) Past Weather	Latitude (°N)	Longitude (°W)
30 cont.				5.5	91	45	4	46.6	124.7
				5.5	92	45	4	48.1	125.6
				5.5	91	45	4	48.2	125.2
				5.5	93	45	4	43.7	124.7
				5.5	92	45	4	44.0	124.9
				5.3	93	28	4	48.4	124.6
				3.5	96	10	2	43.2	124.9
				3.0	96	10	5	44.2	124.7
				3.0	96	10	5	48.3	125.5
				5.1	96	10	4	48.5	126.0
				5.5	91	41	4	48.8	127.8
				5.5	94	45	4	49.1	126.7
				4.0	94	43	2	43.1	124.9
31 Aug 1974	58	6	1	3.1	95	15	4	44.0	124.9
				5.5	92	45	4	49.7	128.9
				3.5	97	10	2	34.0	124.9
				3.1	--	--	4	48.4	126.0
				4.0	95	43	2	43.2	124.9
				3.1	97	05	4	48.4	125.9
1 Sept 1974	79	4	0	5.5	96	40	4	47.9	125.3
				3.5	97	10	2	30.8	116.7
				3.5	94	10	2	47.5	124.7
				5.3	97	28	4	35.3	129.7
2 Sept 1974	74	17	7	2.5	92	12	2	48.4	125.0
				4.3	90	47	5	46.9	124.7
				3.1	97	02	4	48.3	125.7
				4.0	90	40	2	46.2	124.2
				4.6	96	28	2	34.2	120.0
				5.5	90	45	4	46.2	124.2
				4.0	94	45	2	43.8	124.7
				5.1	95	10	4	42.1	124.6
				5.5	90	45	4	46.2	124.2
				5.1	96	10	4	37.5	128.3
				2.6	97	10	0	45.6	125.1
				3.5	97	10	2	45.7	128.3
				4.0	92	45	2	46.2	124.2
				3.6	95	41	0	48.3	124.7
				5.5	93	43	4	43.8	124.7
				4.0	94	43	2	44.0	124.6
				3.1	96	01	4	46.2	124.2

Day	Total # of Ship Reports	# of Foggers	VIS less 1000 m	Duration	(VV) Visibility	(ww) Present Weather	(w) Past Weather	Latitude (°N)	Longitude (°W)
3 Sept 1974	59	11	1	5.5	97	40	4	43.8	124.6
				3.6	93	47	0	49.8	127.8
				5.5	97	40	4	43.9	124.6
				5.1	95	10	4	37.2	124.7
				5.1	96	10	4	36.7	126.2
				3.6	--	40	-	38.2	125.2
				2.6	--	10	-	48.8	127.4
				5.1	94	10	4	37.3	124.1
				5.1	97	10	4	35.8	121.7
				3.5	96	10	2	46.8	124.4
				3.6	97	40	1	48.5	125.3
4 Sept 1974	68	11	1	3.5	96	10	2	47.4	125.0
				4.5	97	40	2	48.5	126.0
				1.0	97	11	2	48.4	125.3
				3.5	96	10	2	48.2	125.6
				4.0	97	41	2	48.5	125.9
				5.5	96	40	4	45.9	129.8
				4.0	97	41	2	49.0	127.5
				4.0	93	43	2	48.4	125.4
				5.5	95	41	4	45.2	127.9
				5.3	95	28	4	47.8	124.5
				1.0	96	12	2	49.3	126.4
5 Sept 1974	53	13	4	3.1	98	01	4	44.6	126.0
				1.0	96	12	2	48.8	126.2
				1.0	97	12	2	48.8	121.6
				4.0	93	41	2	47.9	125.4
				5.1	97	10	4	30.5	116.8
				5.5	93	42	4	47.4	125.2
				4.3	95	41	5	48.3	124.1
				4.0	92	42	2	49.3	126.5
				5.5	93	47	4	33.7	120.5
				3.5	97	10	2	32.7	117.5
				3.0	98	11	4	47.3	124.7
				4.0	96	41	2	48.4	123.4
				5.5	94	45	4	48.5	125.3
Total	1262	318	82						

Day	Total # of Ship Reports	# of Foggers	VIS less 1000 m	Duration	(VV) Visibility	(ww) Present Weather	(w) Past Weather	Latitude (°N)	Longitude (°W)
1 Dec 1975	30	8	1	4.3	97	43	5	46.2	124.2
				4.3	96	47	5	46.2	124.2
				4.3	95	47	5	46.2	124.2
				4.3	94	47	5	46.2	124.2
				5.5	95	41	4	50.0	128.7
				4.3	95	45	5	46.2	124.2
				3.6	91	47	1	41.7	126.7
				5.5	97	43	4	36.9	123.0
2 Dec 1975	38	14	1	3.6	95	43	6	46.5	127.5
				4.3	98	45	5	35.7	122.1
				4.3	95	47	5	46.2	124.2
				5.5	97	41	4	42.5	125.8
				1.0	93	63	6	45.2	124.4
				4.3	96	45	5	46.2	124.2
				1.0	94	53	5	43.7	124.7
				5.5	97	40	4	43.5	125.8
				3.6	97	41	0	36.7	126.1
				3.6	97	45	6	46.2	124.2
				1.0	94	53	5	42.3	125.0
				5.1	97	10	4	37.2	124.3
				3.6	98	41	1	36.1	127.9
				3.0	95	12	4	33.0	124.0
3 Dec 1975	53	15	3	5.5	92	45	4	38.3	123.6
				5.5	92	47	1	36.9	123.2
				4.0	97	43	2	36.6	126.4
				1.0	90	0	5	30.9	123.4
				5.5	95	42	4	39.7	124.6
				3.1	97	1	4	38.0	123.9
				3.6	97	47	0	32.5	118.5
				3.6	95	47	6	46.2	124.2
				3.1	98	5	4	35.6	122.4
				3.0	94	12	4	32.6	118.3
				5.5	94	41	4	31.2	123.7
				3.1	97	0	4	30.6	116.9
				3.6	95	47	6	46.2	124.2
				3.3	98	28	4	39.1	124.1
				2.6	97	10	1	36.9	122.7

Day	Total # of Ship Reports	# of Foggers	VIS less 1000 m	Duration	(VV) Visibility	(ww) Present Weather	(w) Past Weather	Latitude (°N)	Longitude (°W)
4 Dec 1975	44	5	1	5.5	96	47	4	40.8	128.5
				3.6	97	40	1	34.7	121.8
				1.0	94	61	2	42.8	125.0
				1.0	94	50	5	41.4	130.0
				2.5	93	61	2	44.2	124.9
Total	165	42	6						

LEGEND

Fog Location Charts, figures 4-25.

• fogger

× nonfogger

--- duration contour in hours

fog boundary

Sea Surface Temperature Charts, figures 28-44.

—— isotherm (°C)

• data point

Air Temperature Minus Sea Surface Temperature Charts, figures 45-52.

—— isopleths of $(T_a - T_w)$ (°C)

• data point

Surface Trajectories, figures 53-62.

⟵ trajectory

--- isotherm (°C)

••••• daily sea surface temperature boundary

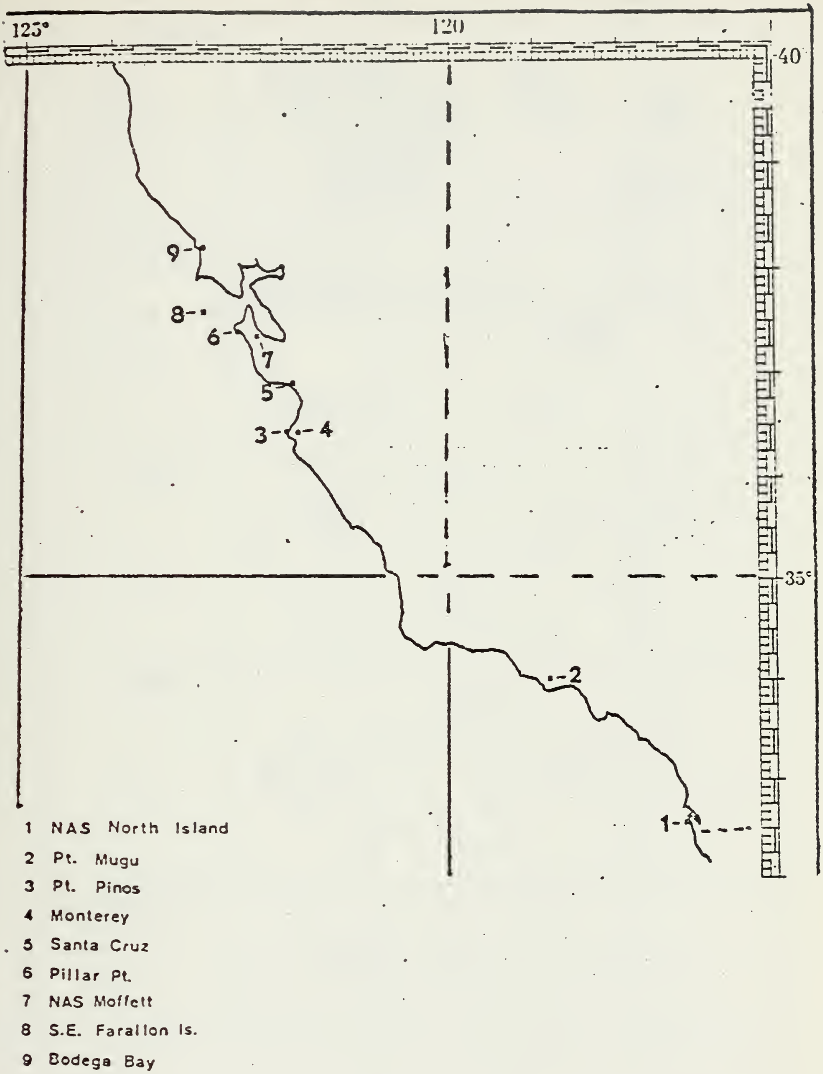

Figure 1. Position of Coastal Observation Sites Studied by Peterson. (Peterson, 1975)

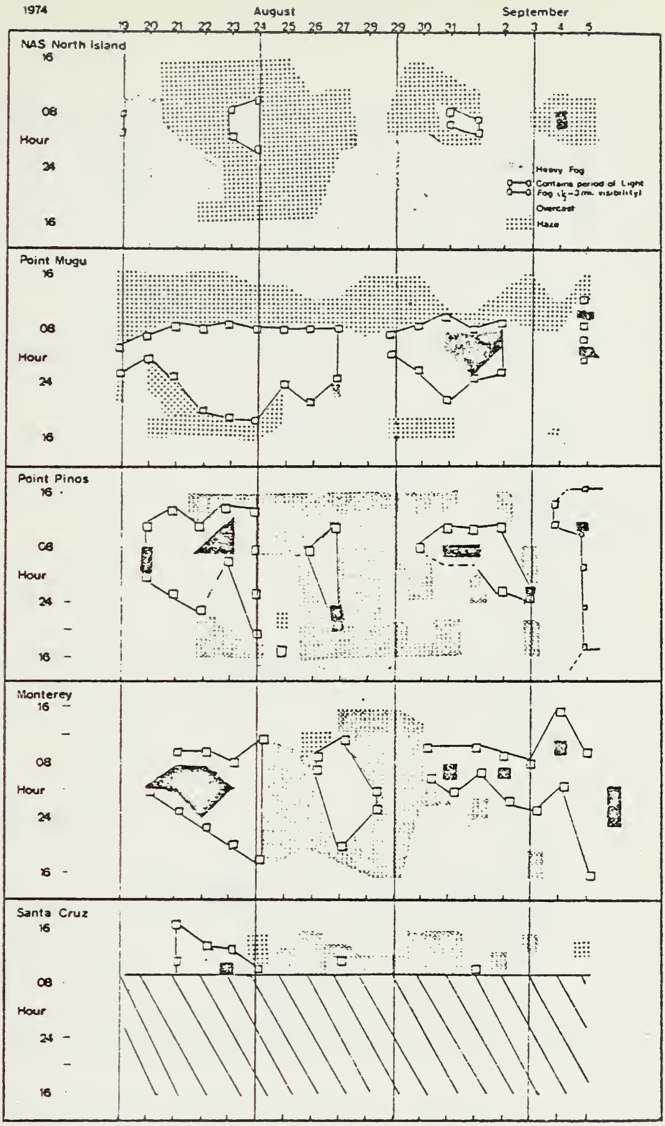

Figure 2. Hourly Visibility and Cloudiness at Coastal Sites. (Peterson, 1975)

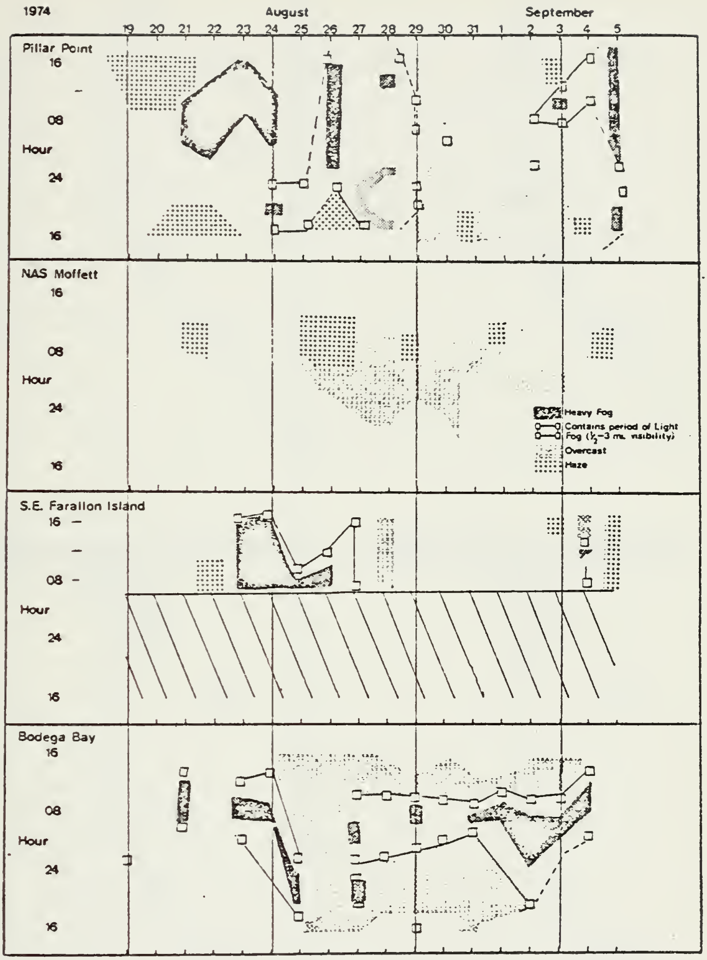

Figure 3. Hourly Visibility and Cloudiness at Coastal Sites. (Peterson, 1975)

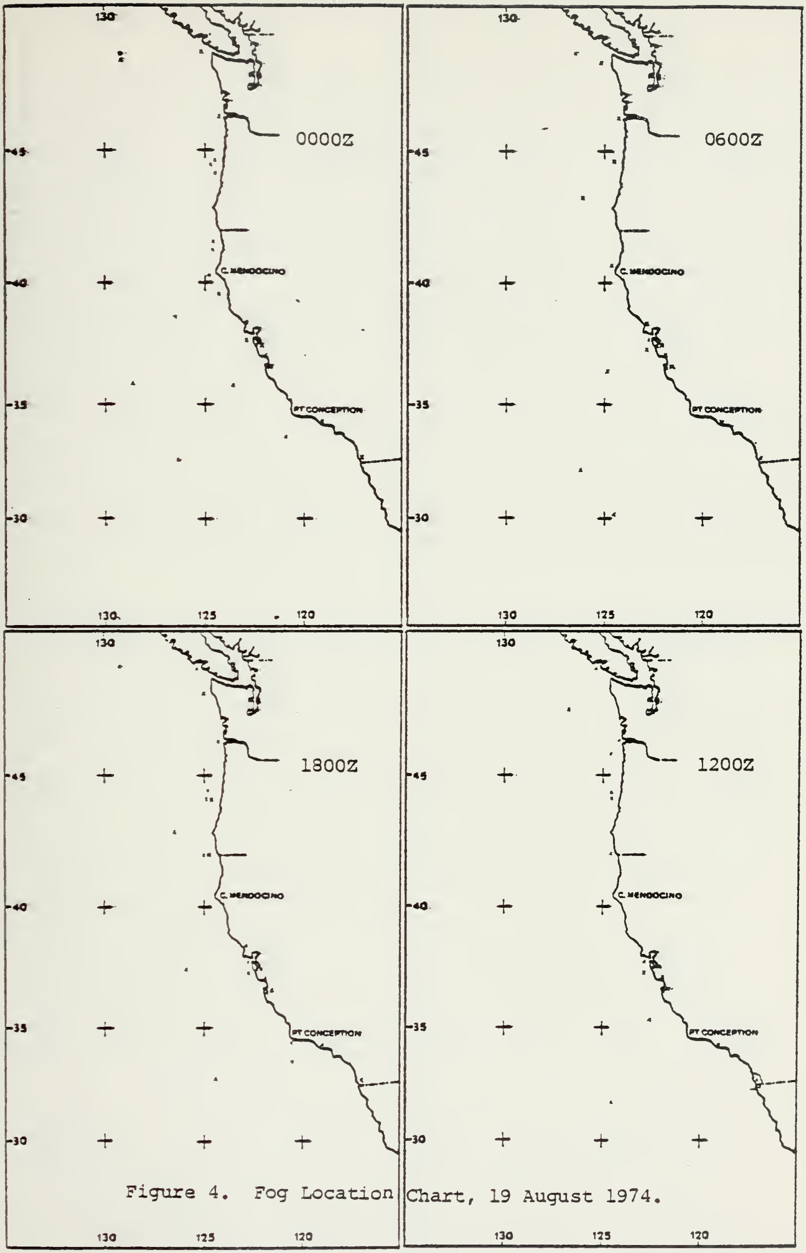

Figure 4. Fog Location Chart, 19 August 1974.

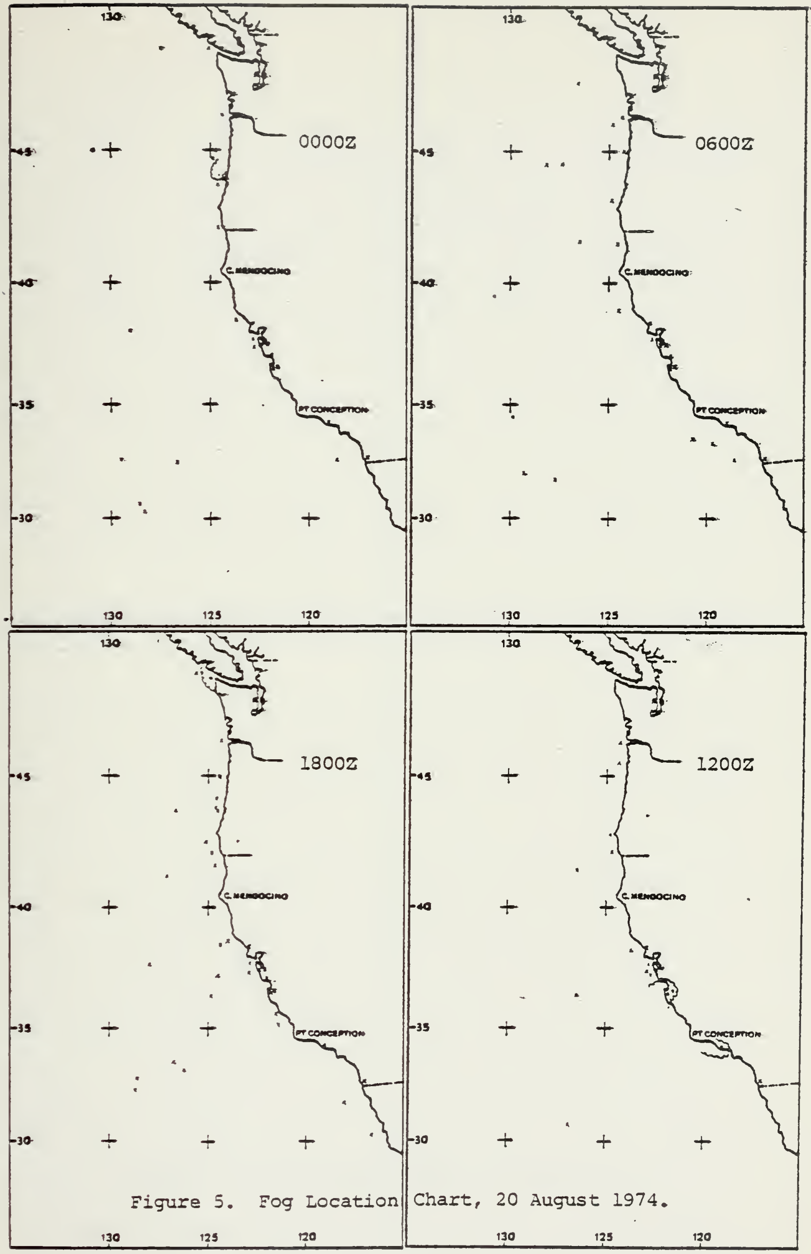

Figure 5. Fog Location Chart, 20 August 1974.

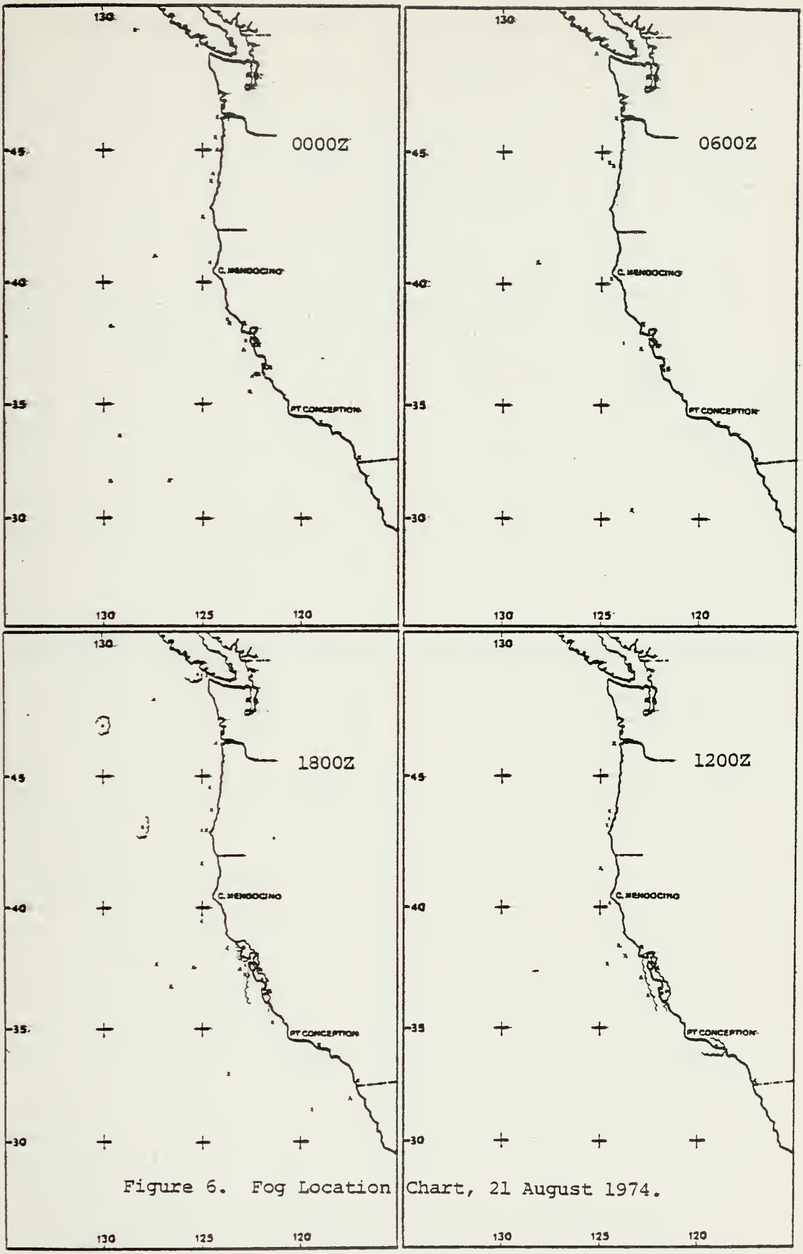

Figure 6. Fog Location Chart, 21 August 1974.

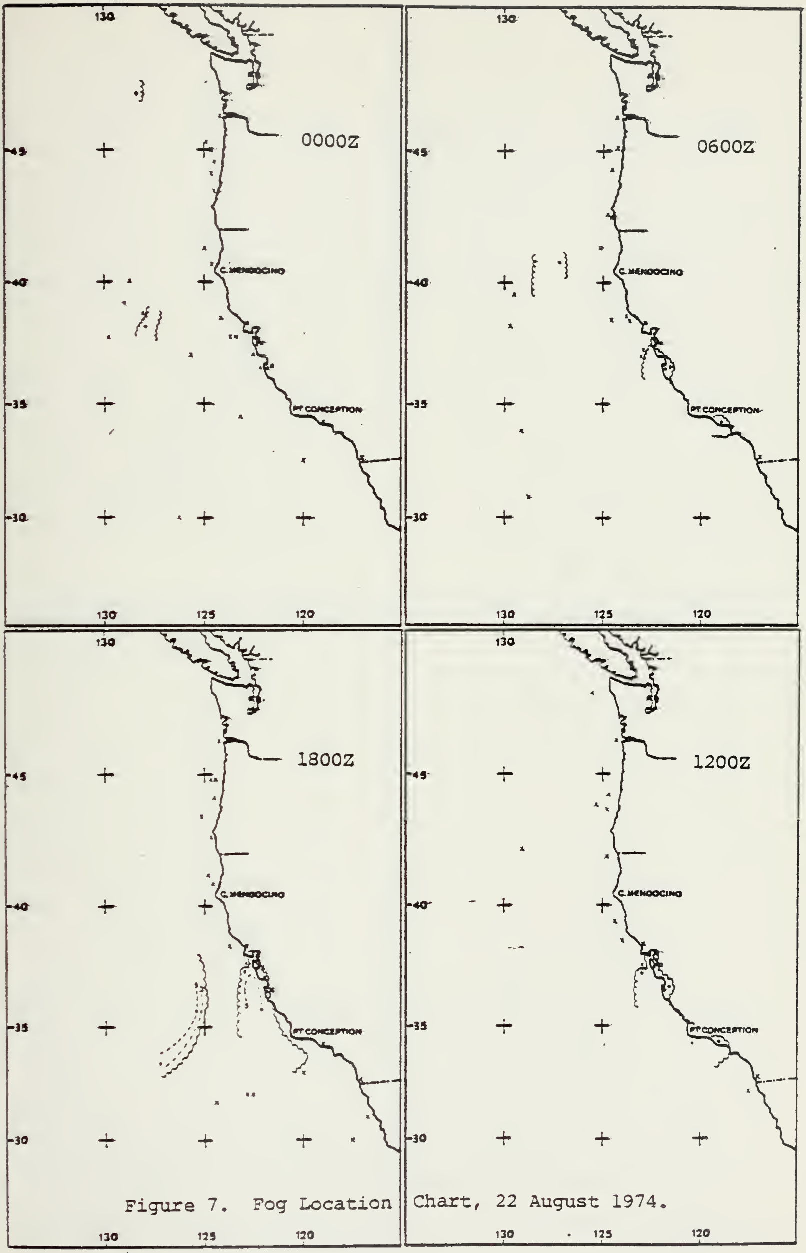

Figure 7. Fog Location Chart, 22 August 1974.

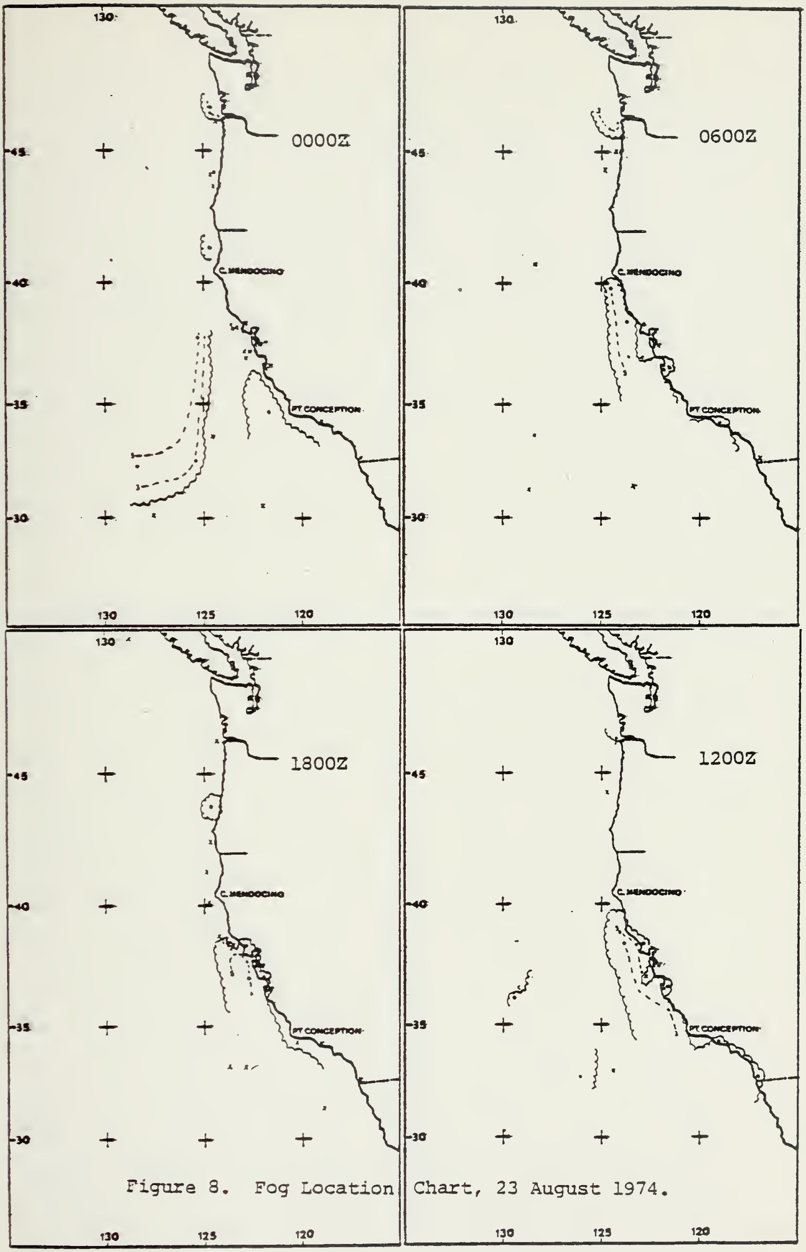

Figure 8. Fog Location Chart, 23 August 1974.

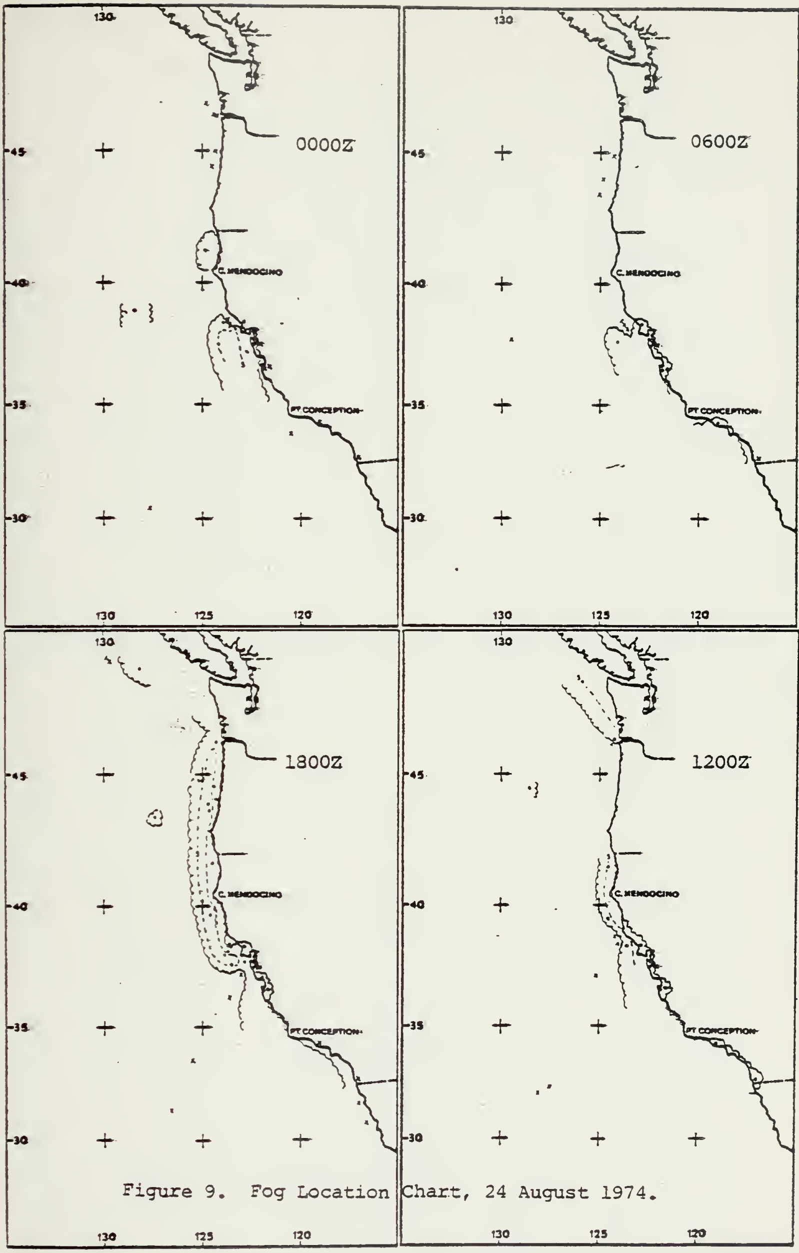

Figure 9. Fog Location Chart, 24 August 1974.

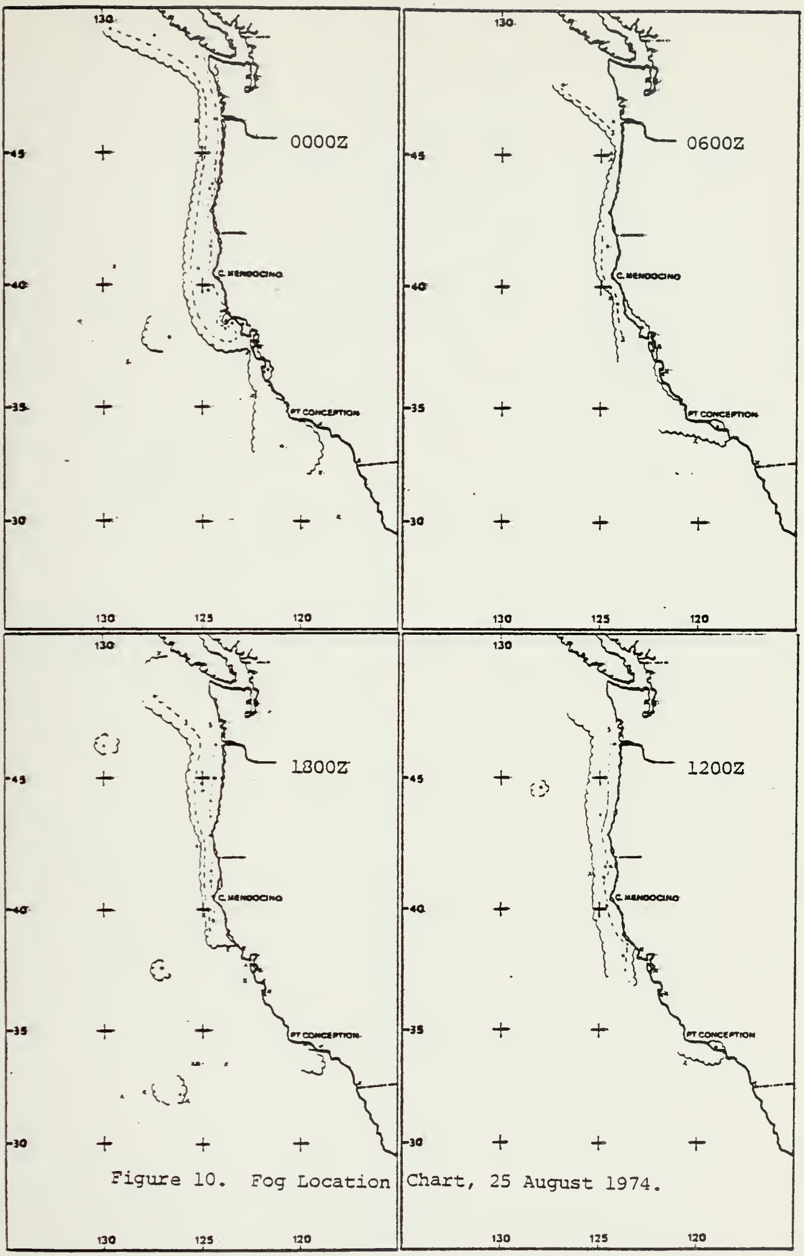

Figure 10. Fog Location Chart, 25 August 1974.

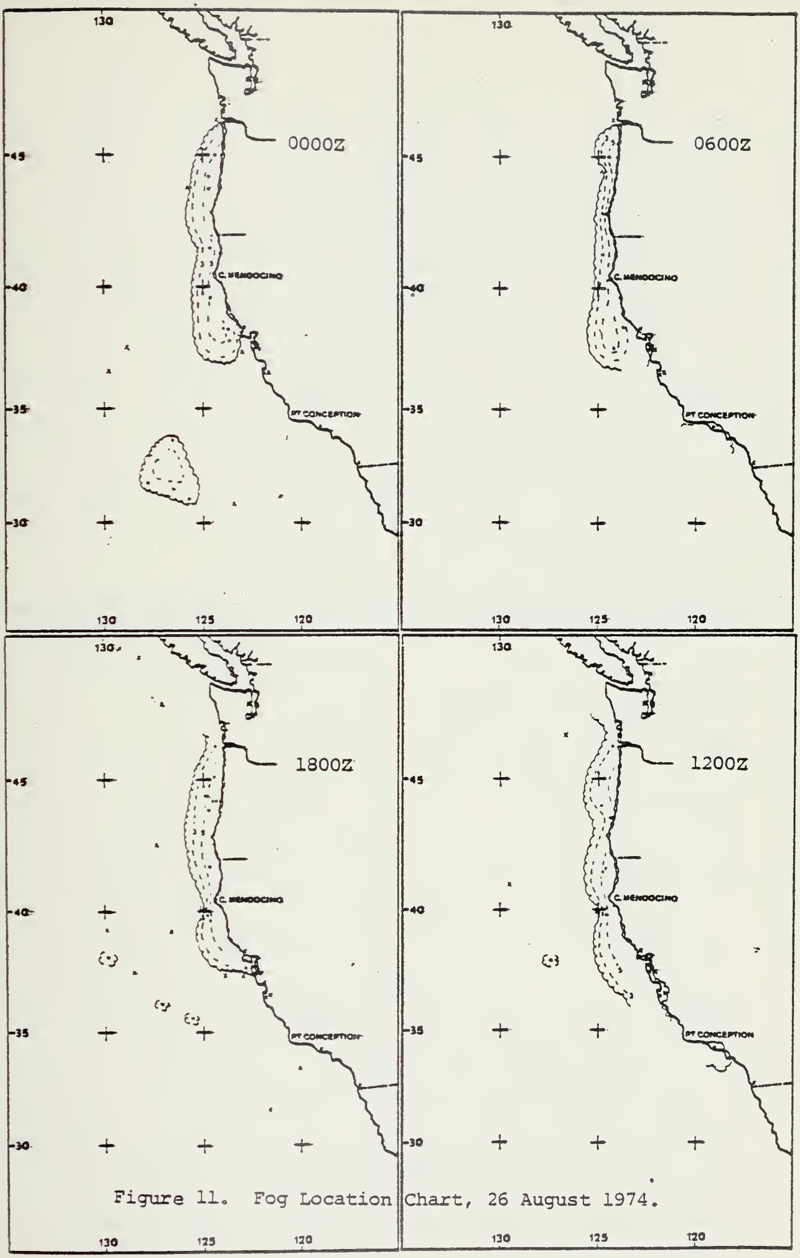

Figure 11. Fog Location Chart, 26 August 1974.

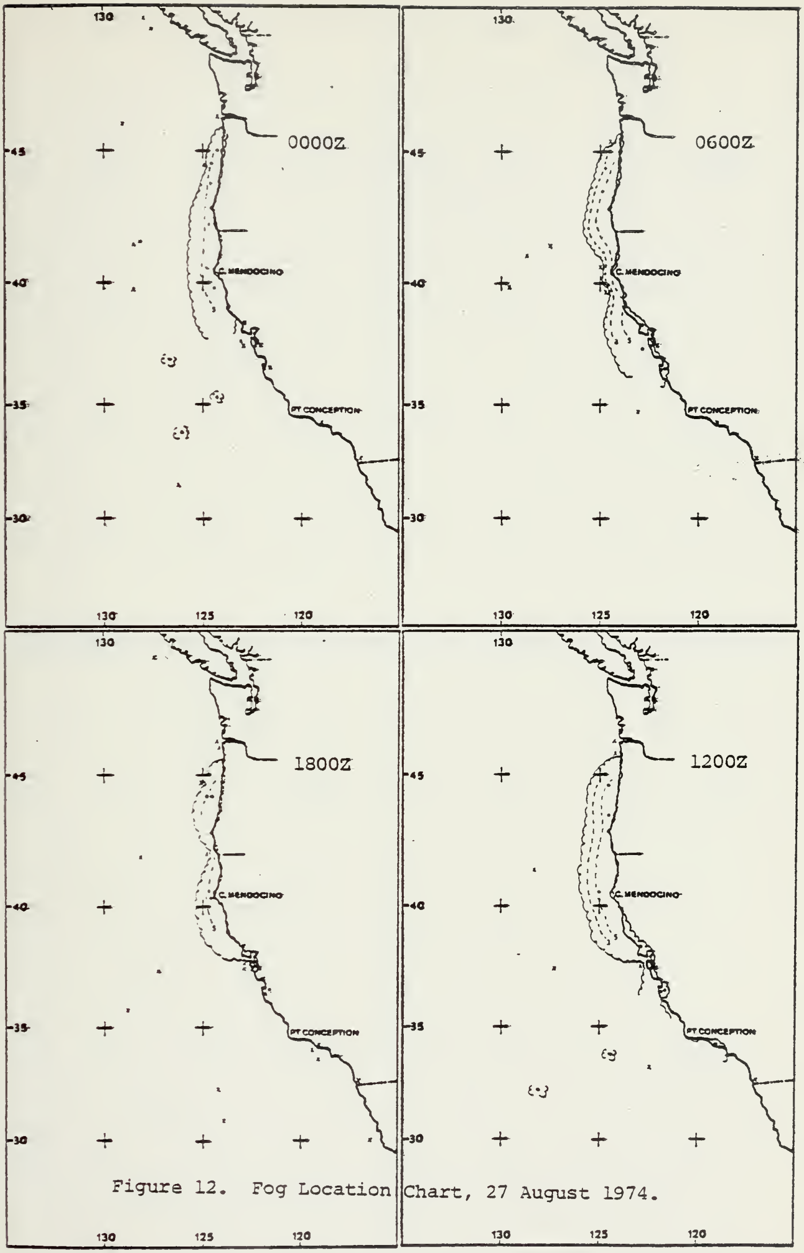

Figure 12. Fog Location Chart, 27 August 1974.

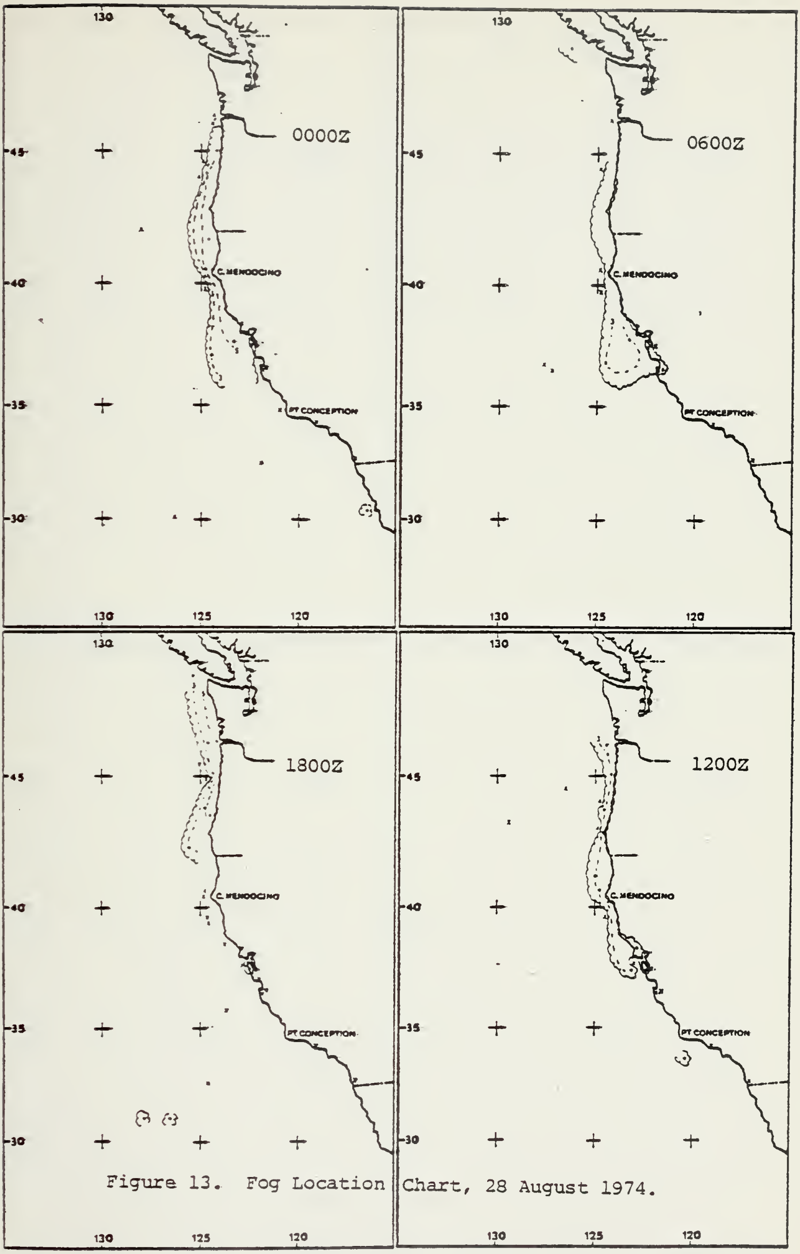

Figure 13. Fog Location Chart, 28 August 1974.

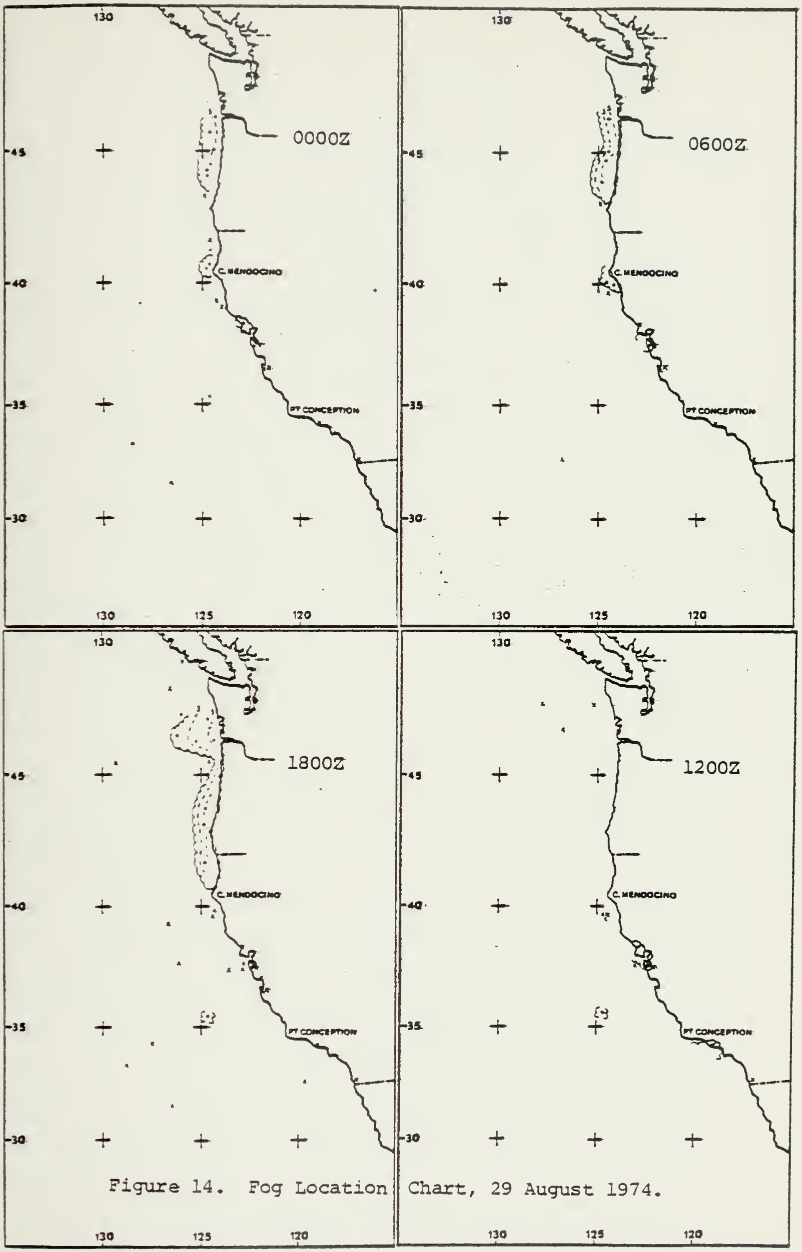

Figure 14. Fog Location Chart, 29 August 1974.

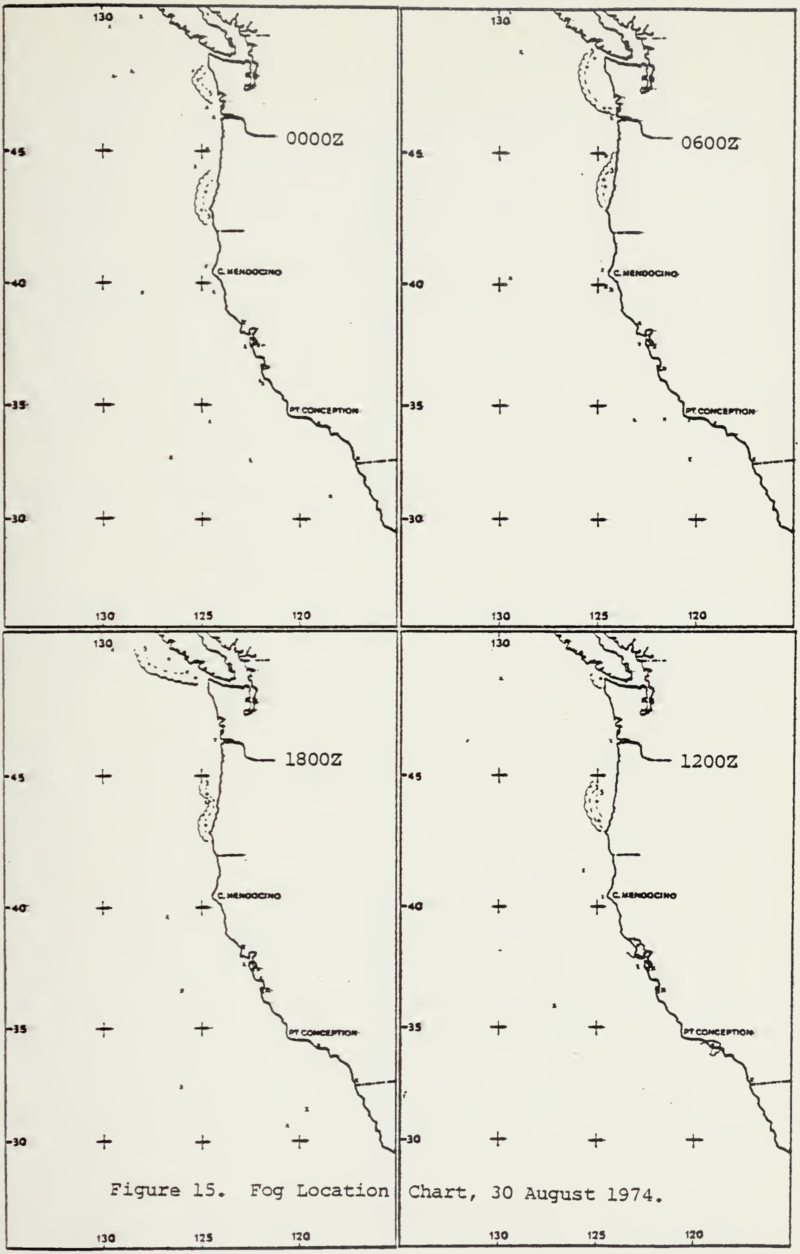

Figure 15. Fog Location Chart, 30 August 1974.

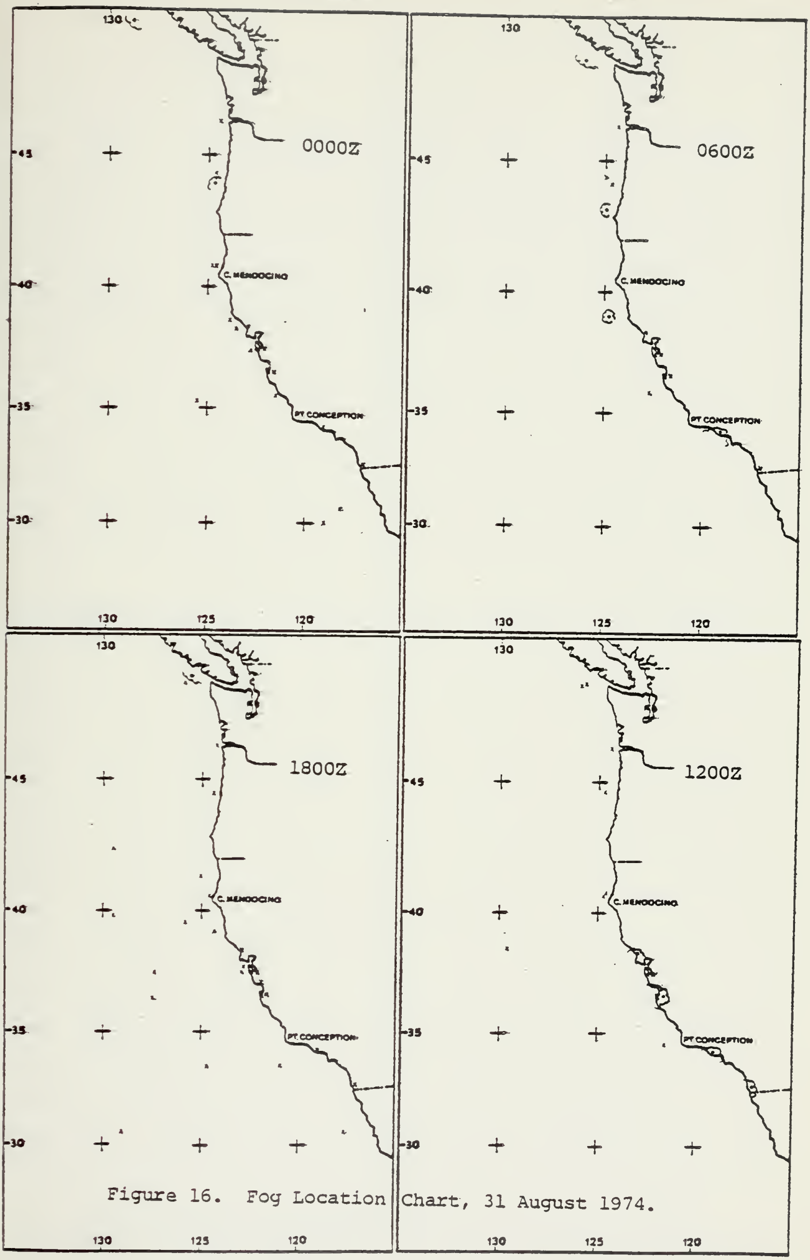

Figure 16. Fog Location Chart, 31 August 1974.

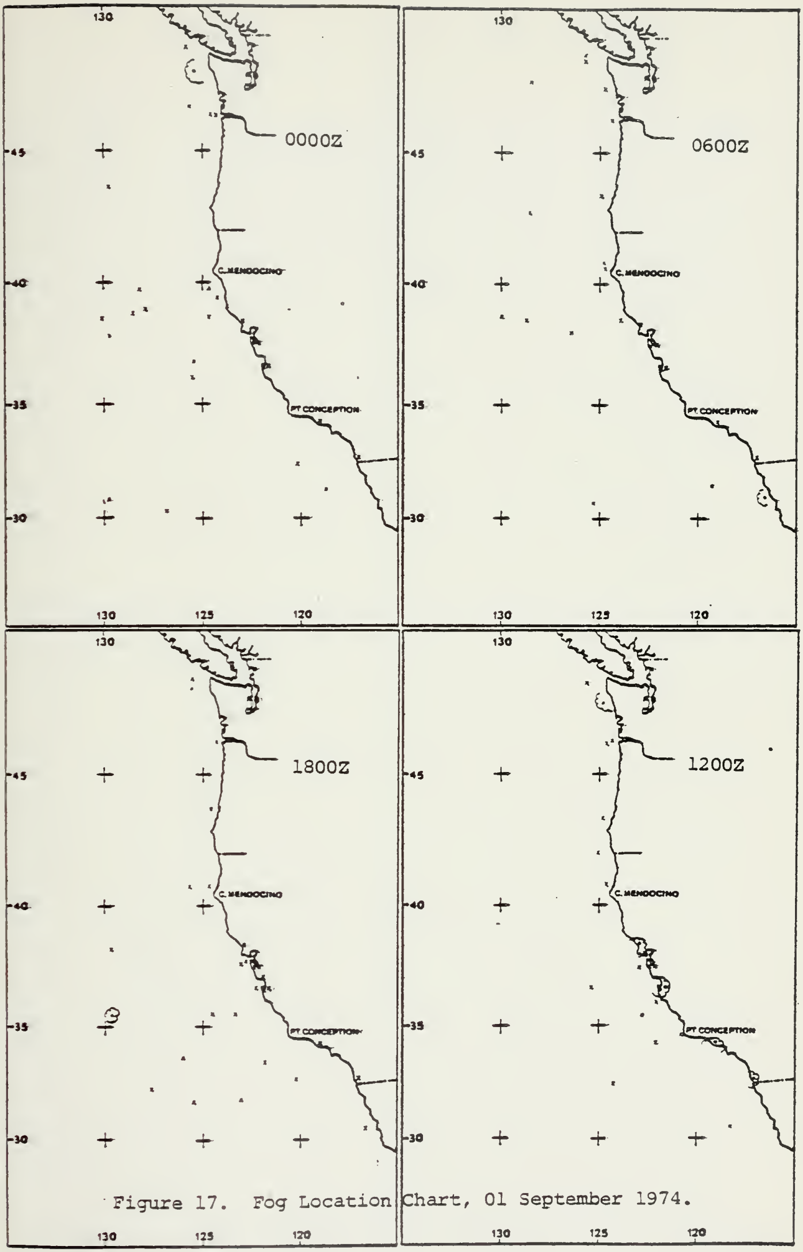

Figure 17. Fog Location Chart, 01 September 1974.

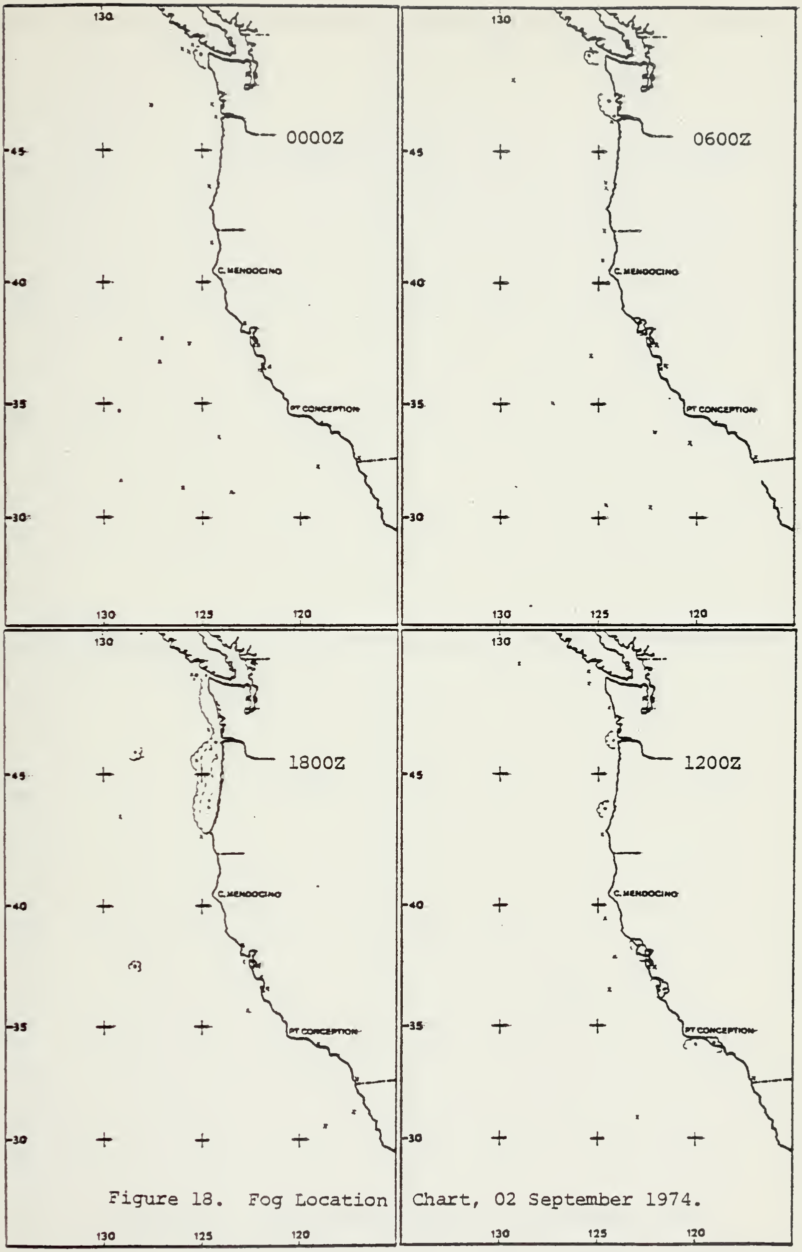

Figure 18. Fog Location Chart, 02 September 1974.

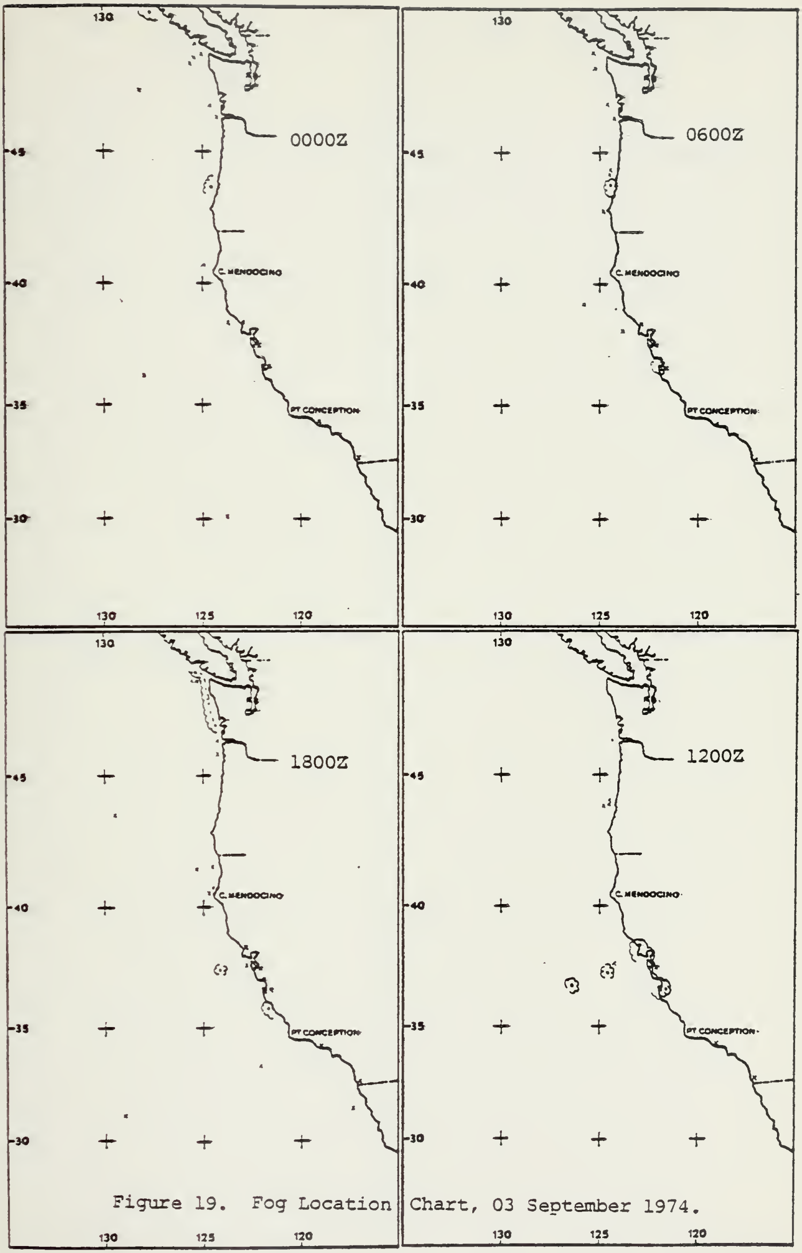

Figure 19. Fog Location Chart, 03 September 1974.

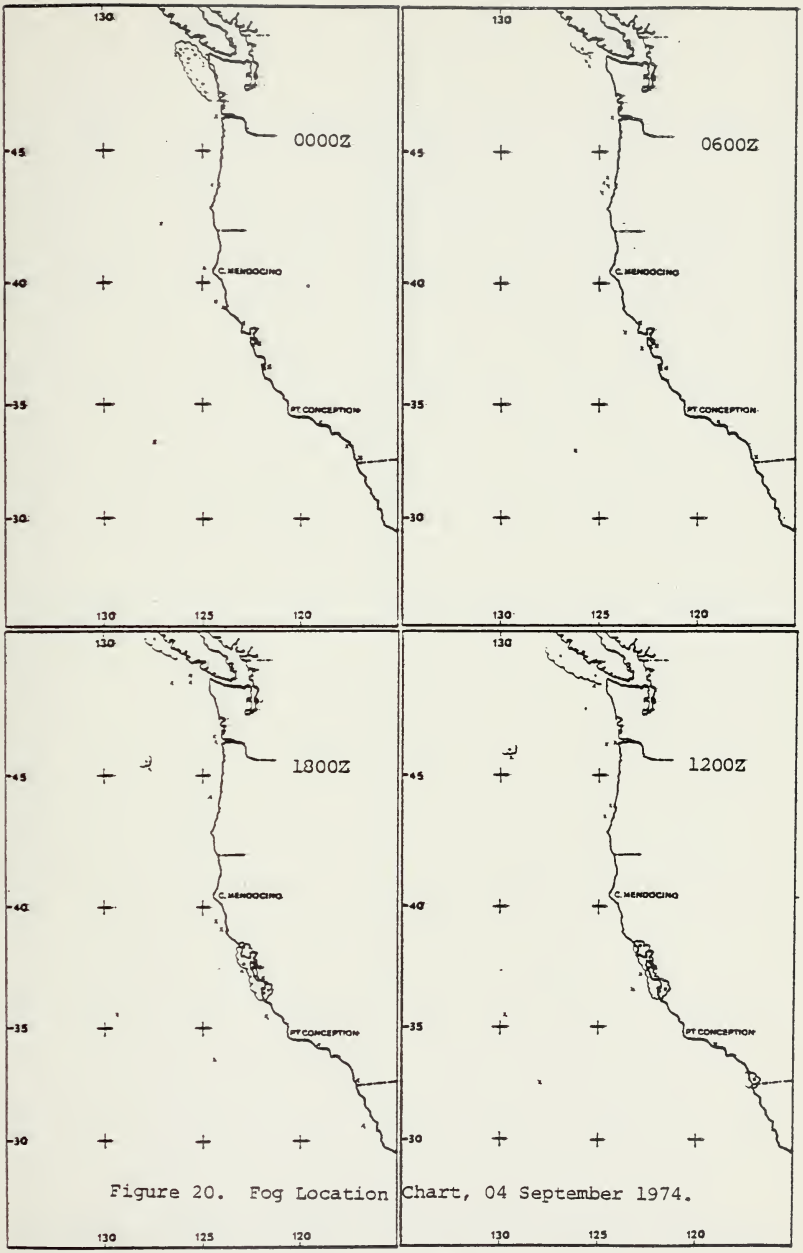

Figure 20. Fog Location Chart, 04 September 1974.

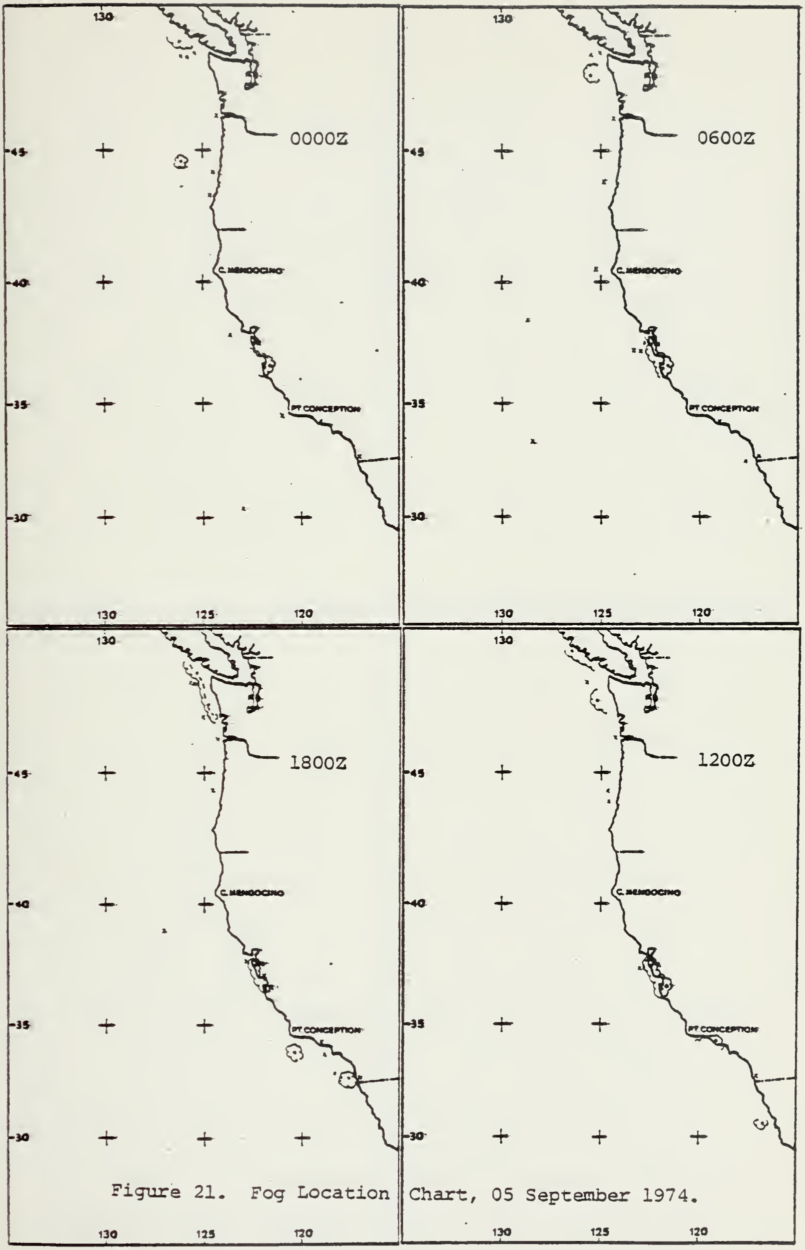

Figure 21. Fog Location Chart, 05 September 1974.

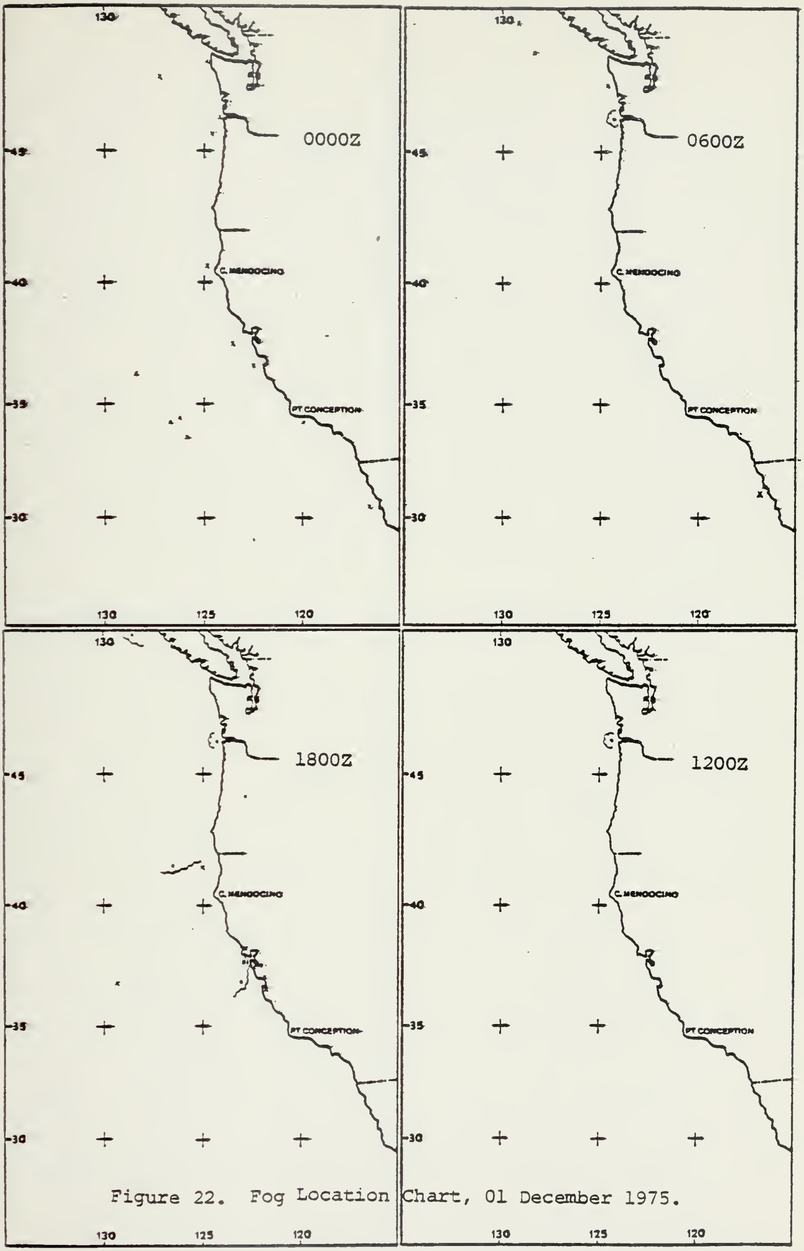

Figure 22. Fog Location Chart, 01 December 1975.

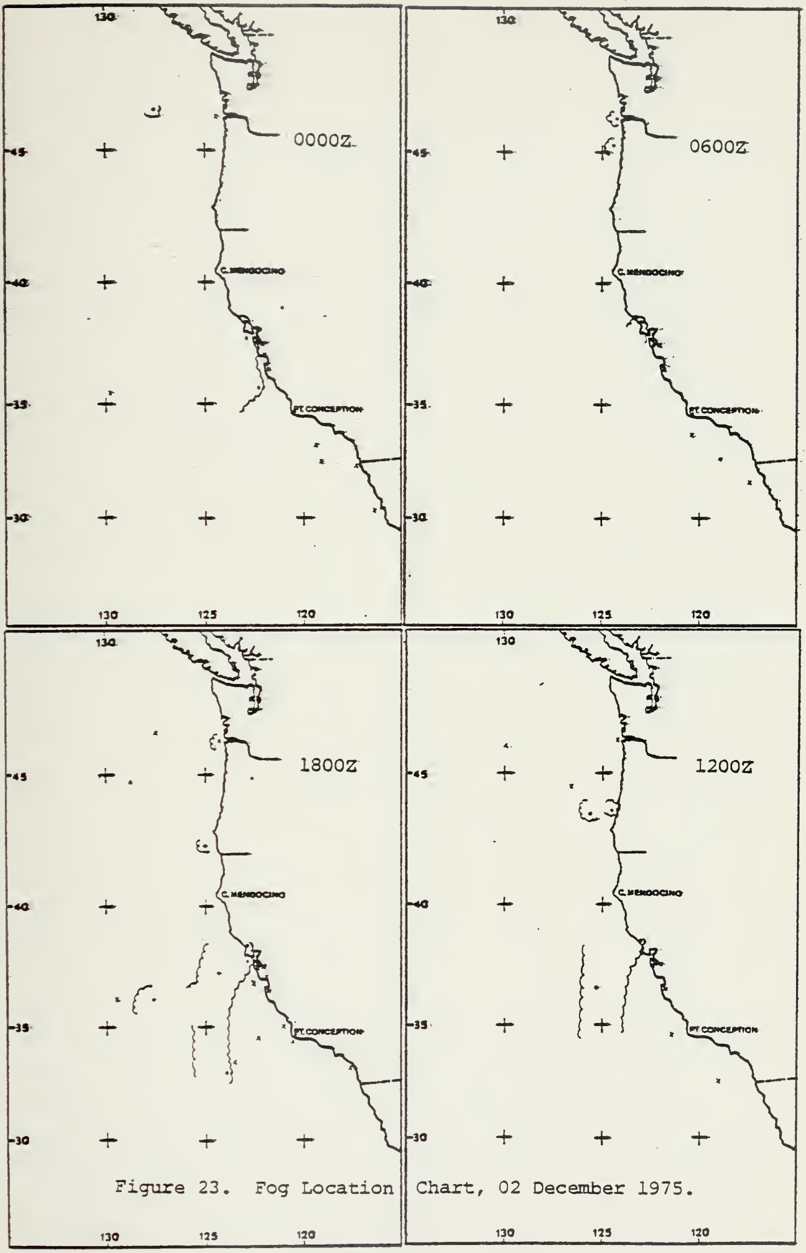

Figure 23. Fog Location Chart, 02 December 1975.

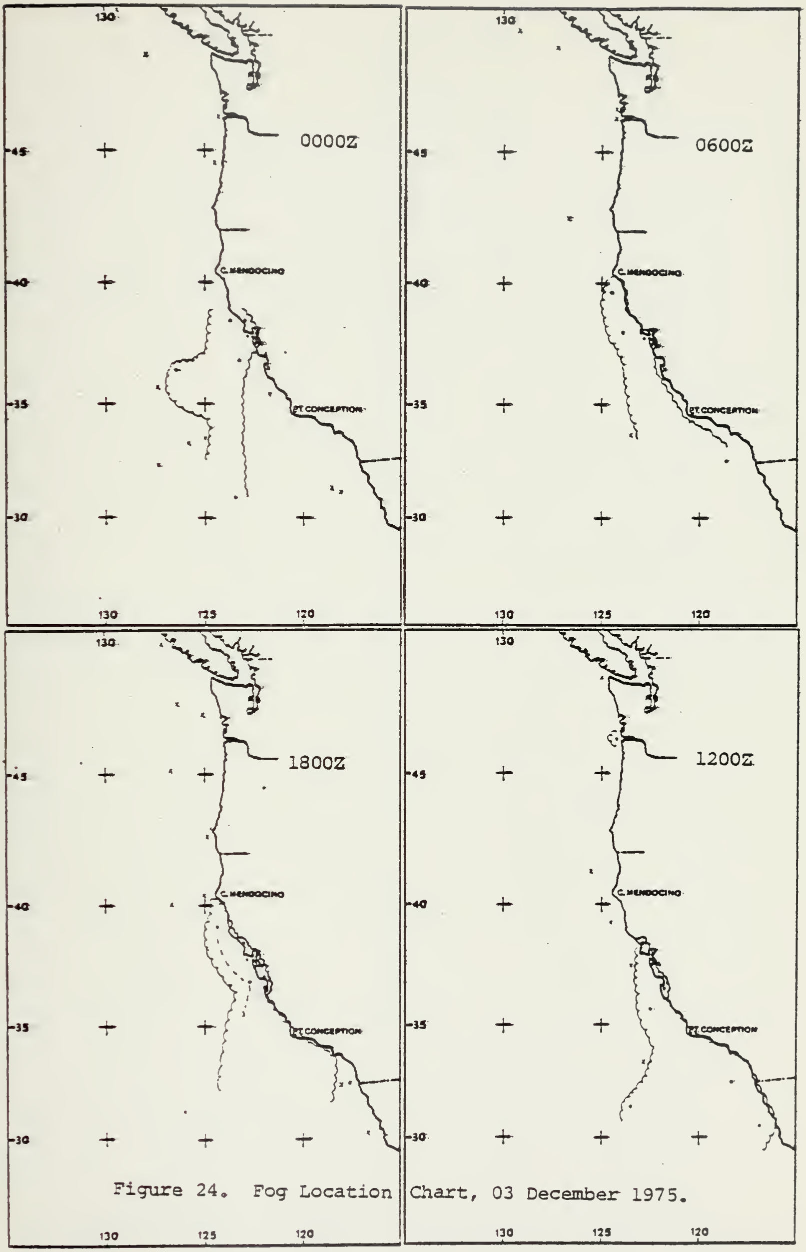

Figure 24. Fog Location Chart, 03 December 1975.

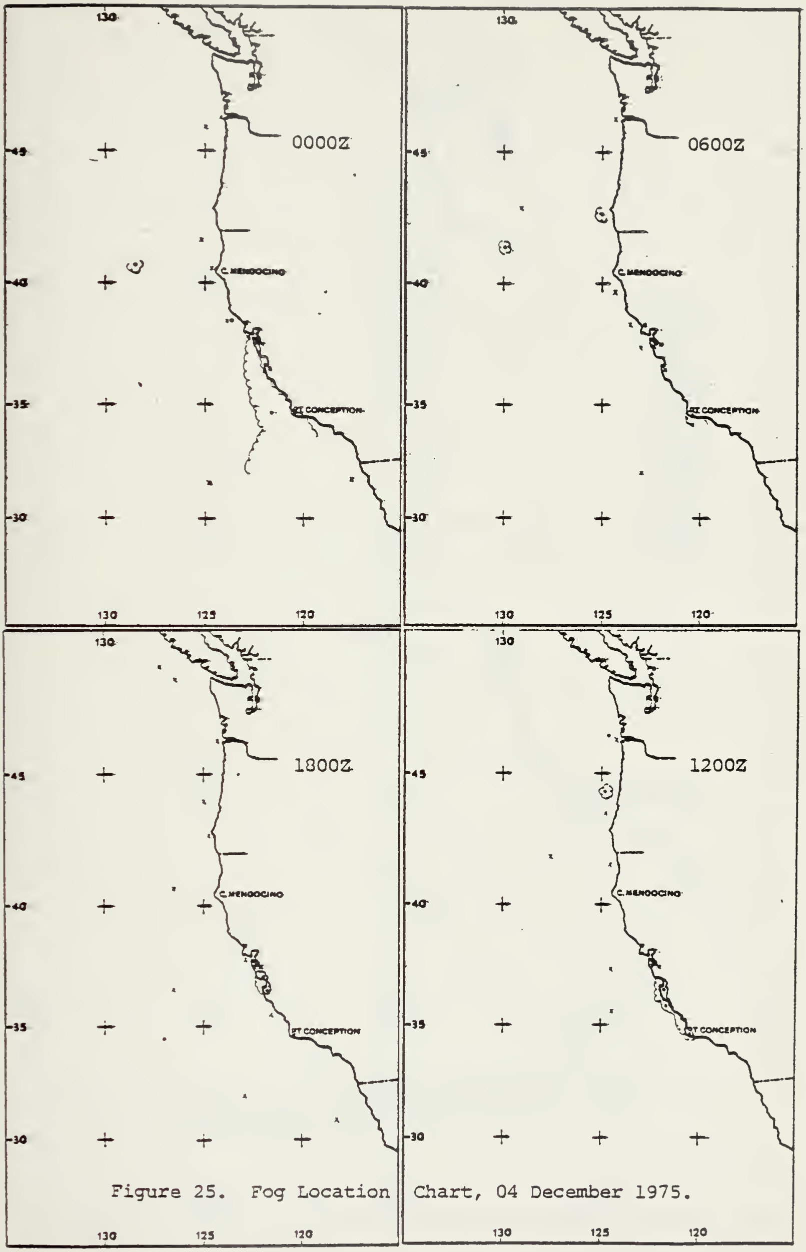

Figure 25. Fog Location Chart, 04 December 1975.

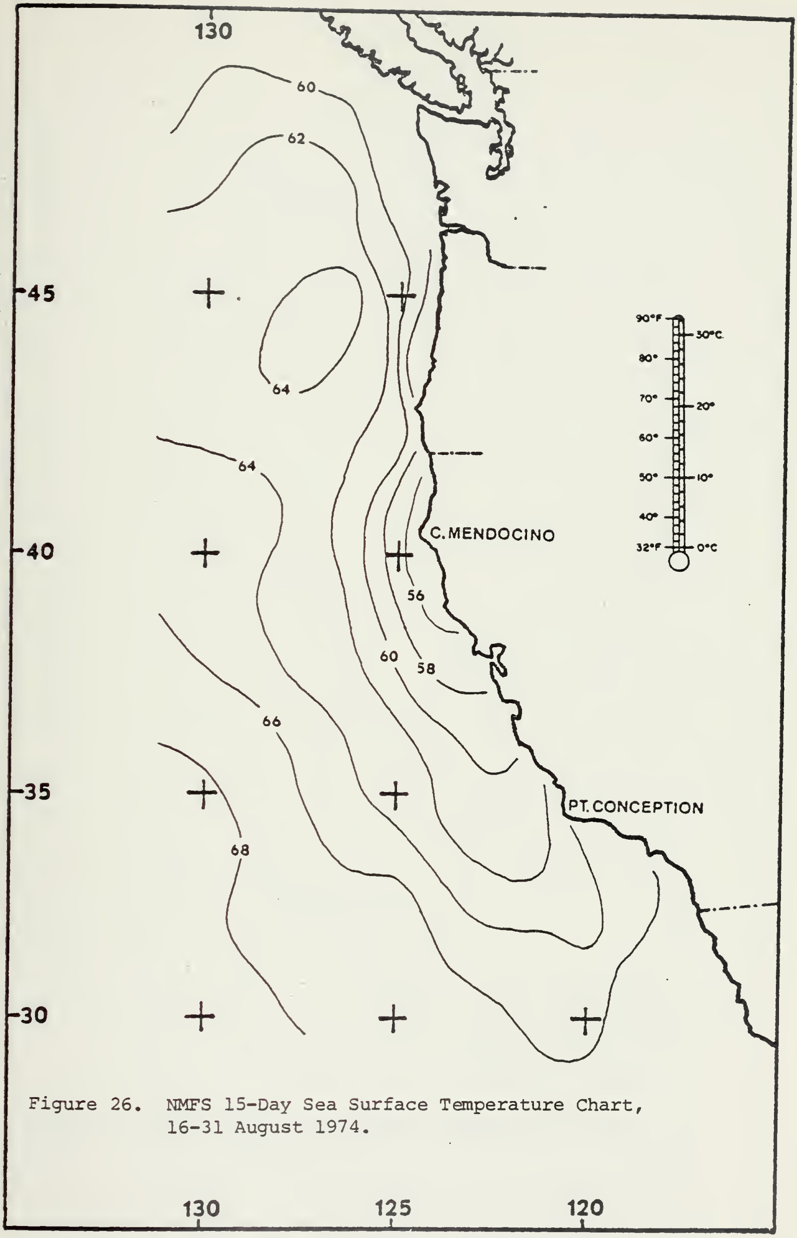

Figure 26. NMFS 15-Day Sea Surface Temperature Chart, 16-31 August 1974.

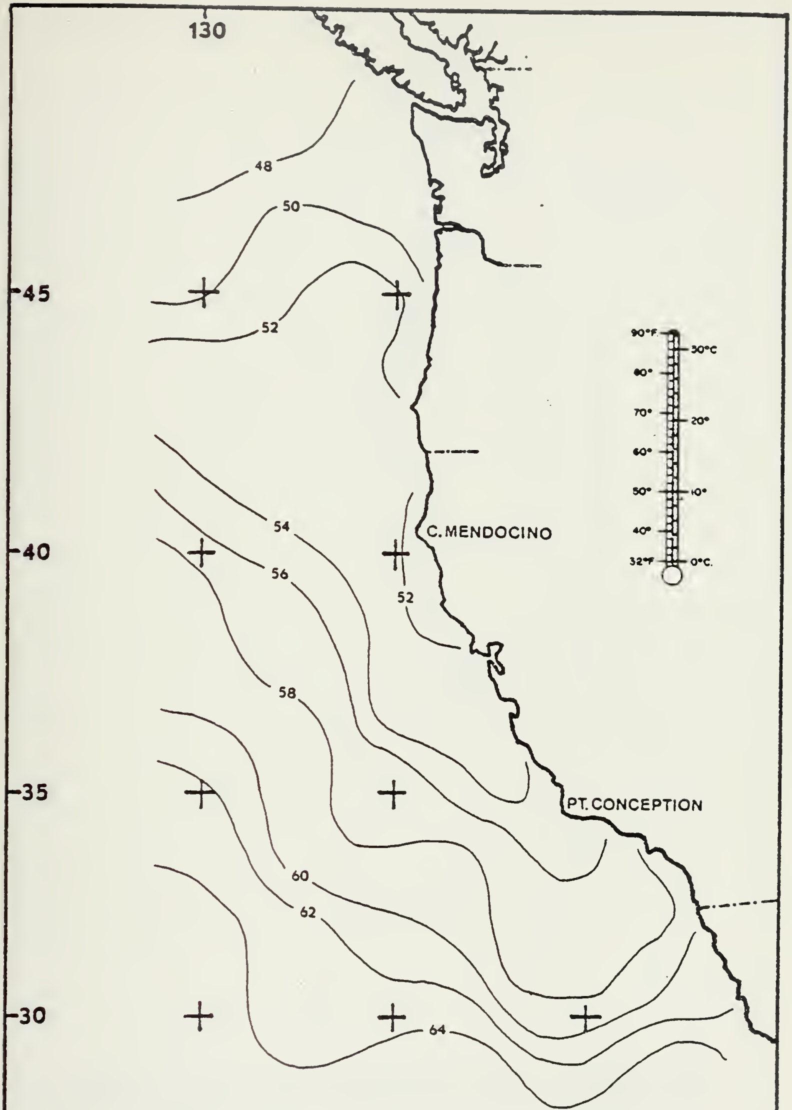

Figure 27. NMFS 15-Day Sea Surface Temperature Chart, 1-15 December 1975.

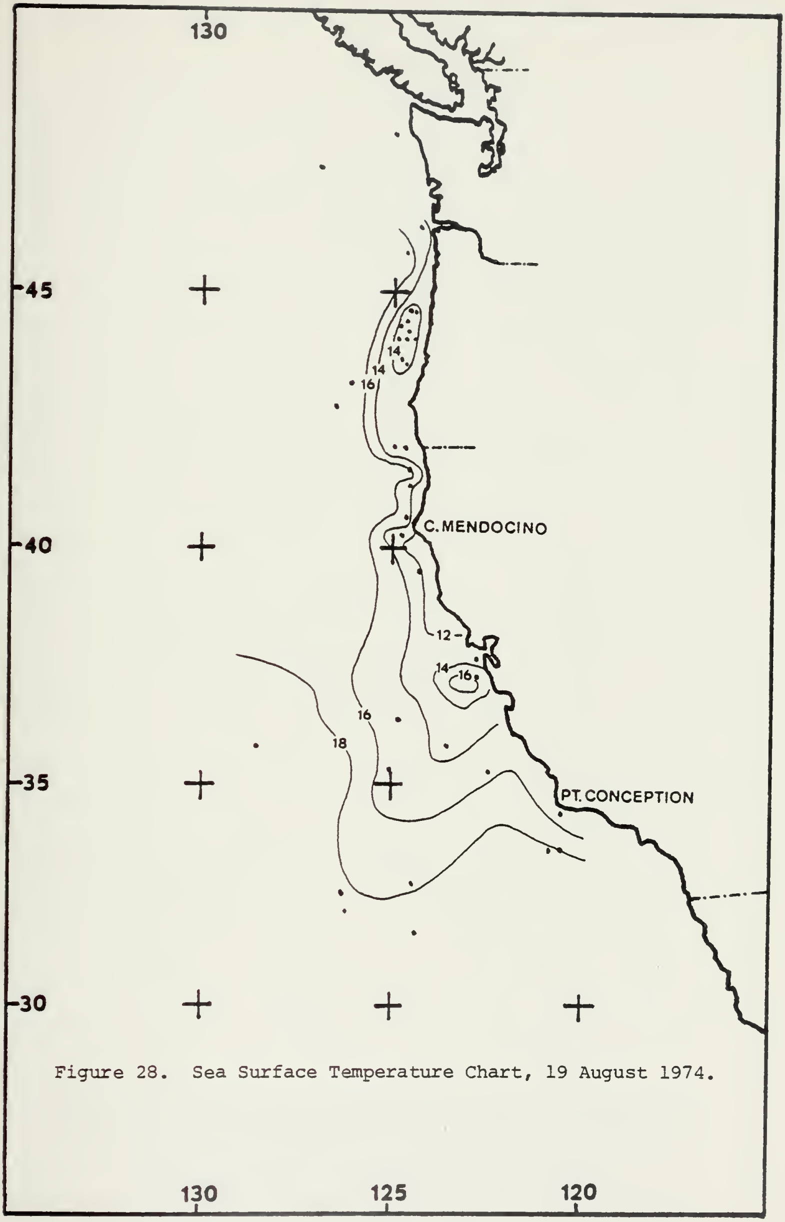

Figure 28. Sea Surface Temperature Chart, 19 August 1974.

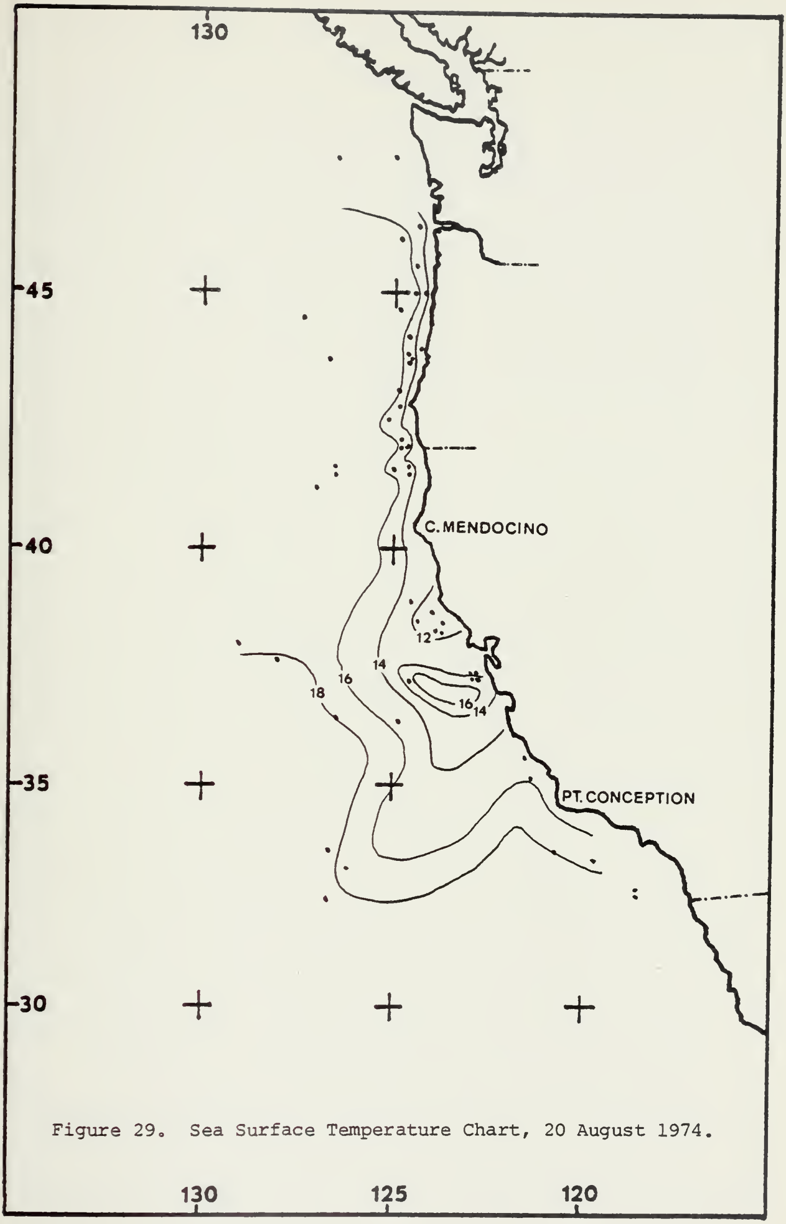

Figure 29. Sea Surface Temperature Chart, 20 August 1974.

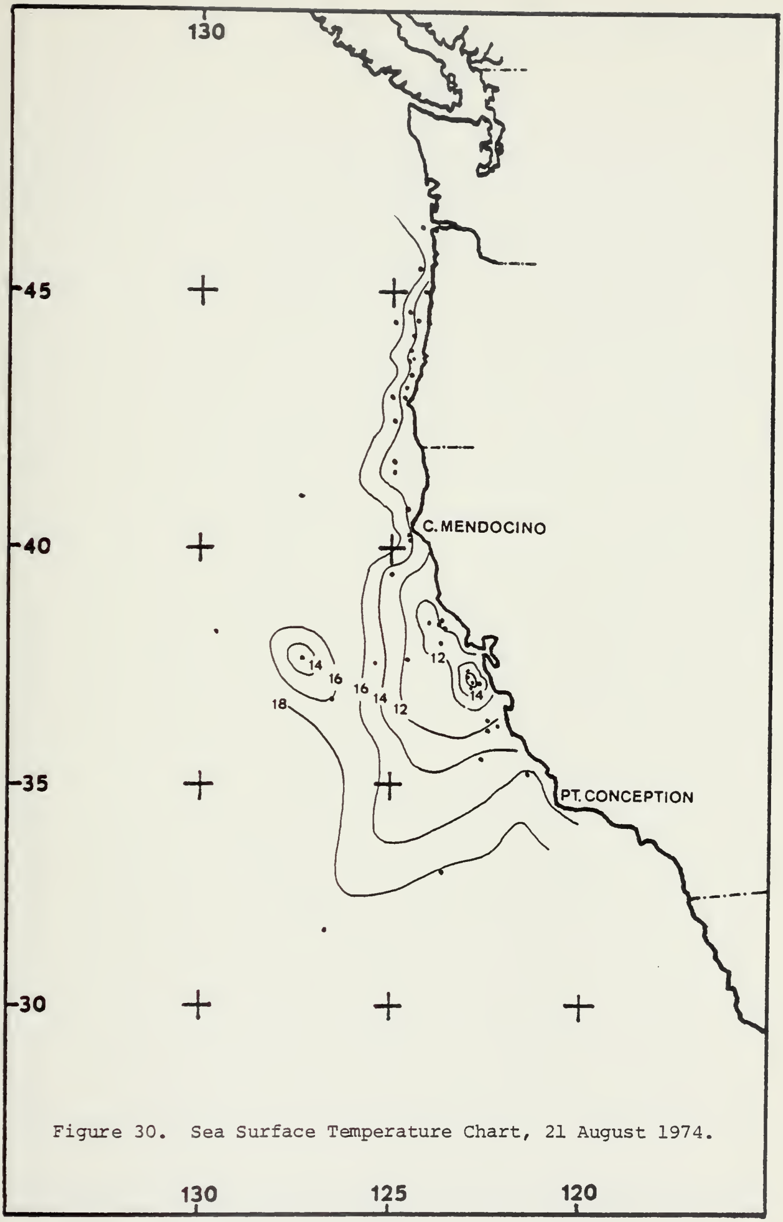

Figure 30. Sea Surface Temperature Chart, 21 August 1974.

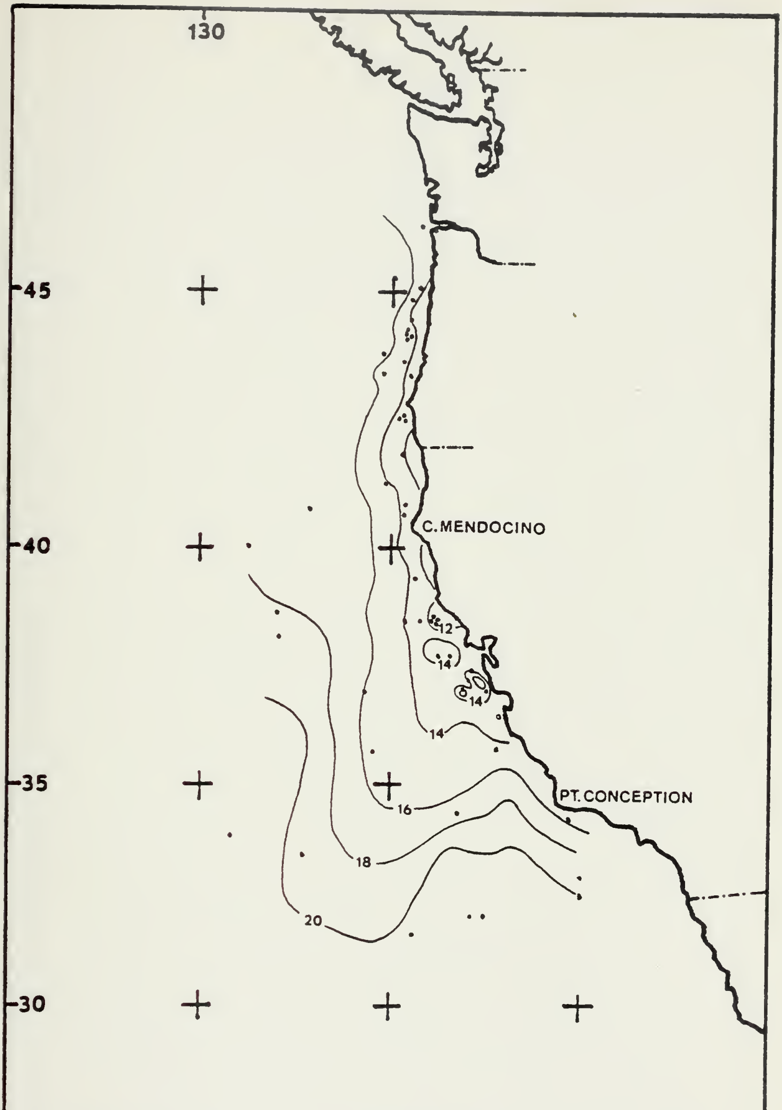

Figure 31. Sea Surface Temperature Chart, 22 August 1974.

130 125 120

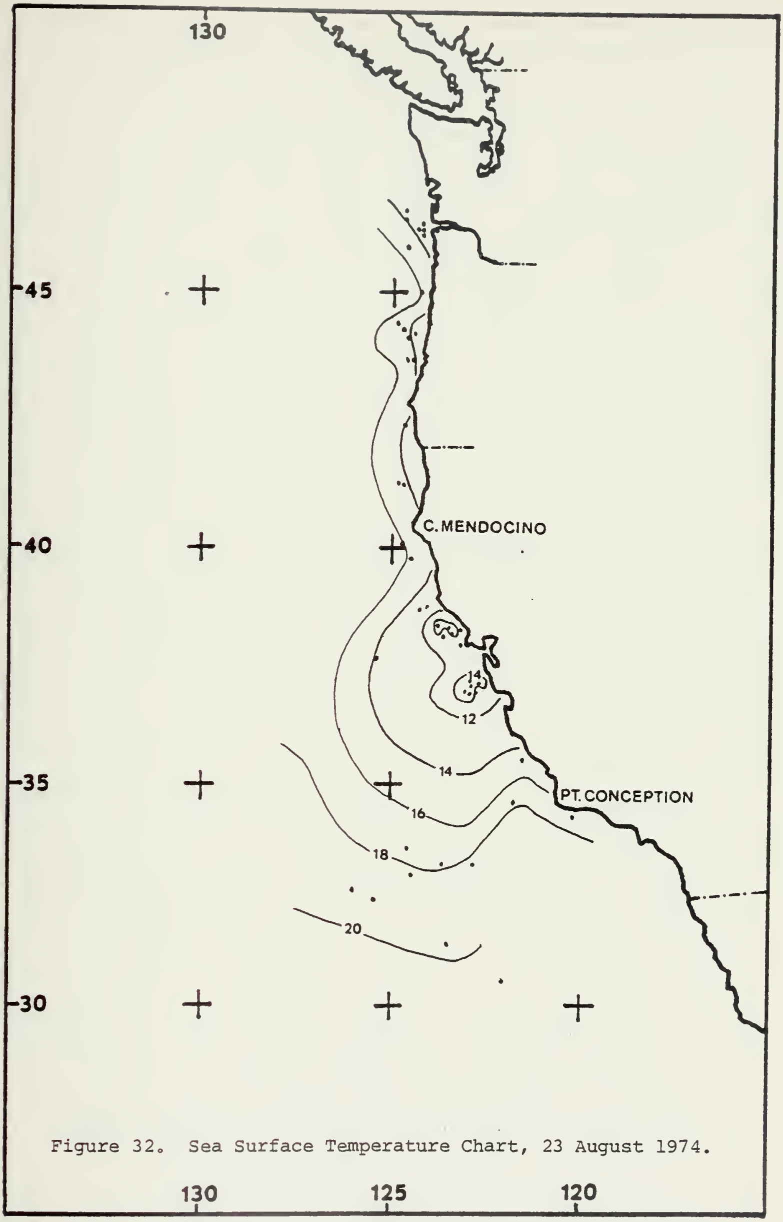

Figure 32. Sea Surface Temperature Chart, 23 August 1974.

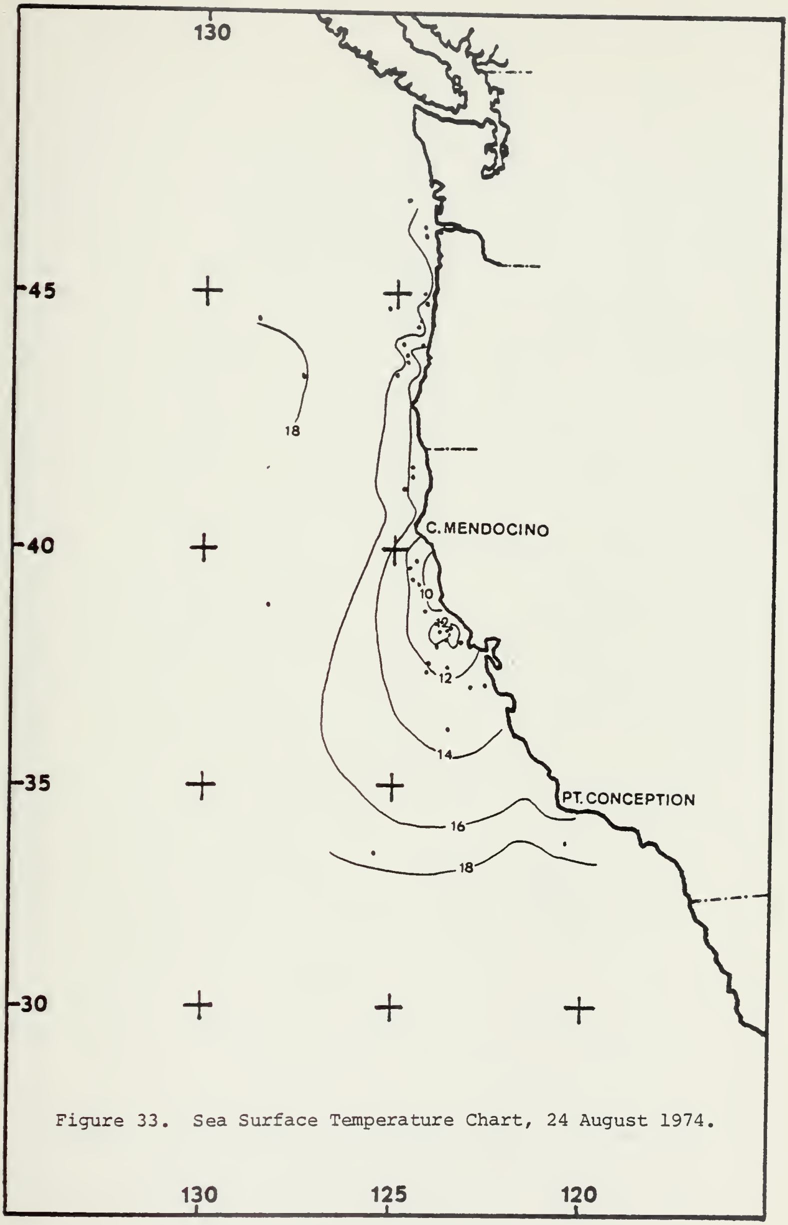

Figure 33. Sea Surface Temperature Chart, 24 August 1974.

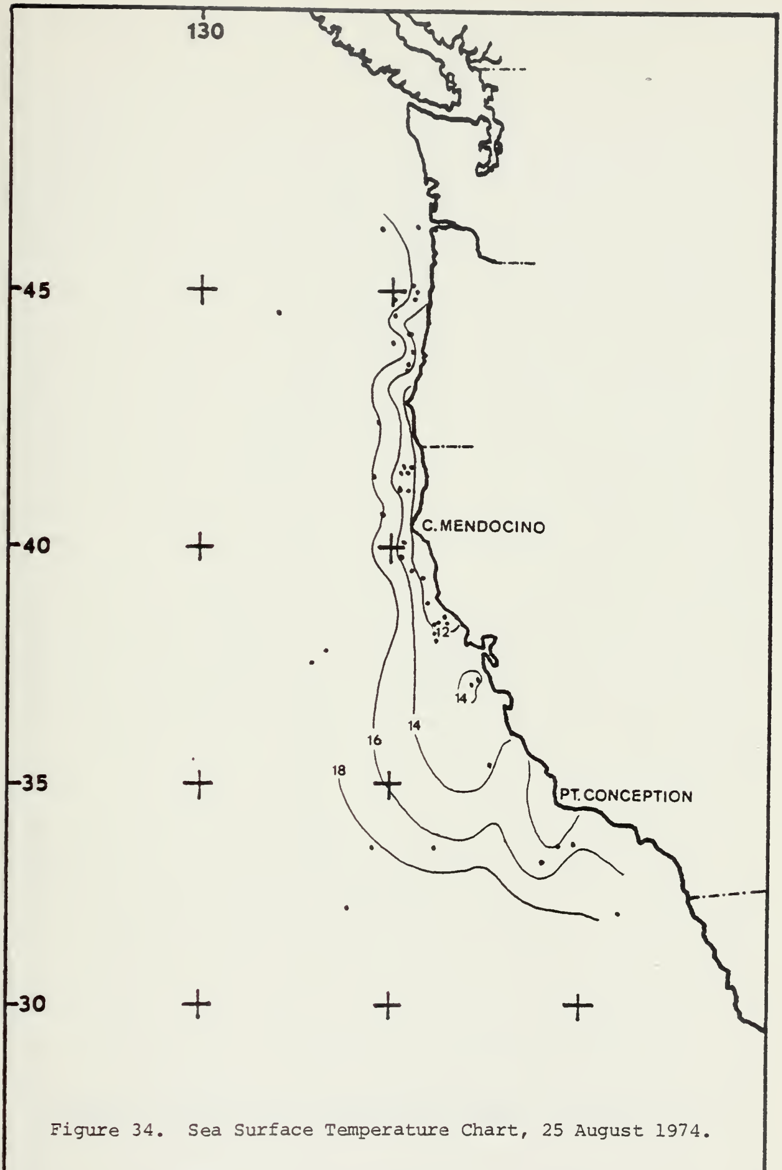

Figure 34. Sea Surface Temperature Chart, 25 August 1974.

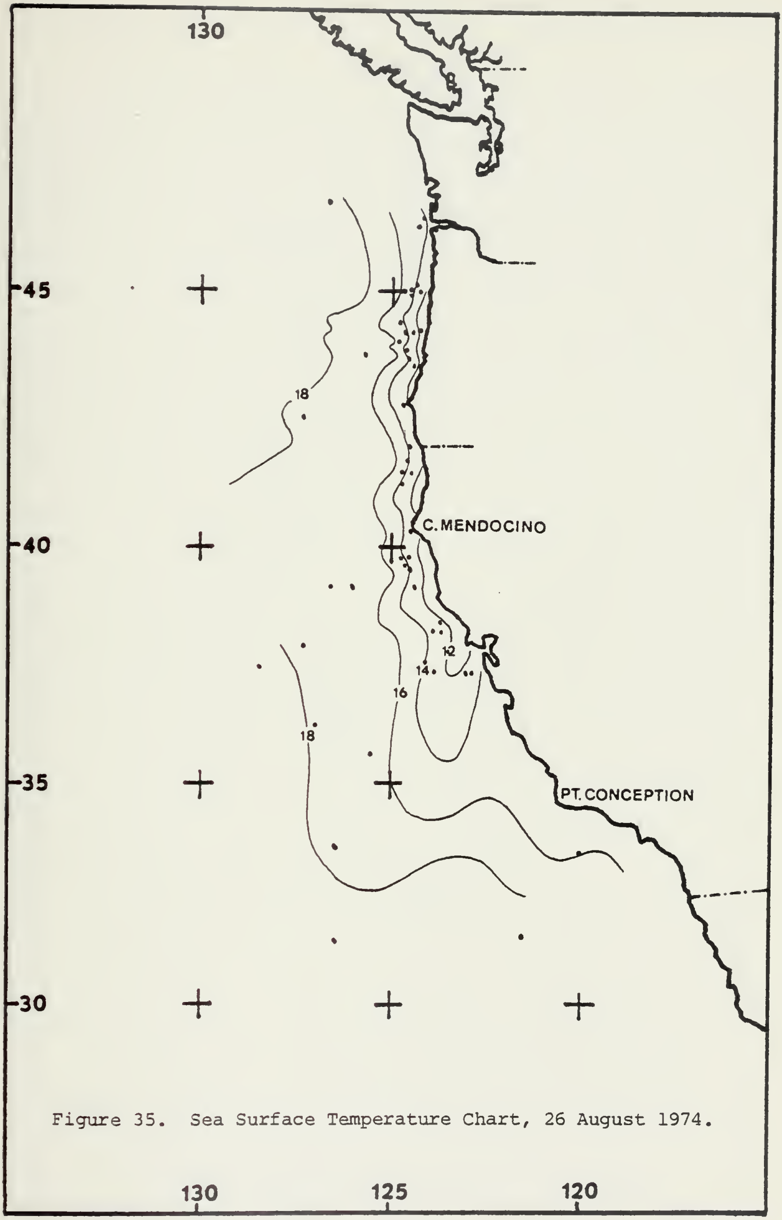

Figure 35. Sea Surface Temperature Chart, 26 August 1974.

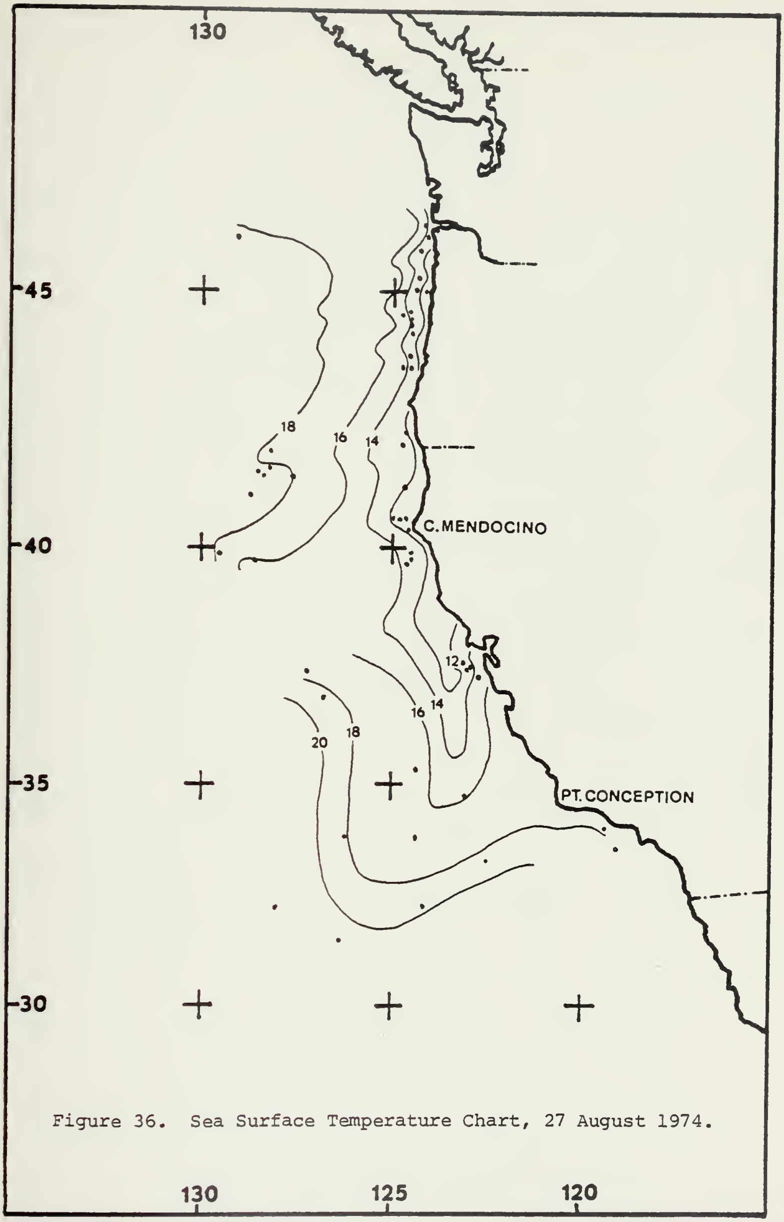

Figure 36. Sea Surface Temperature Chart, 27 August 1974.

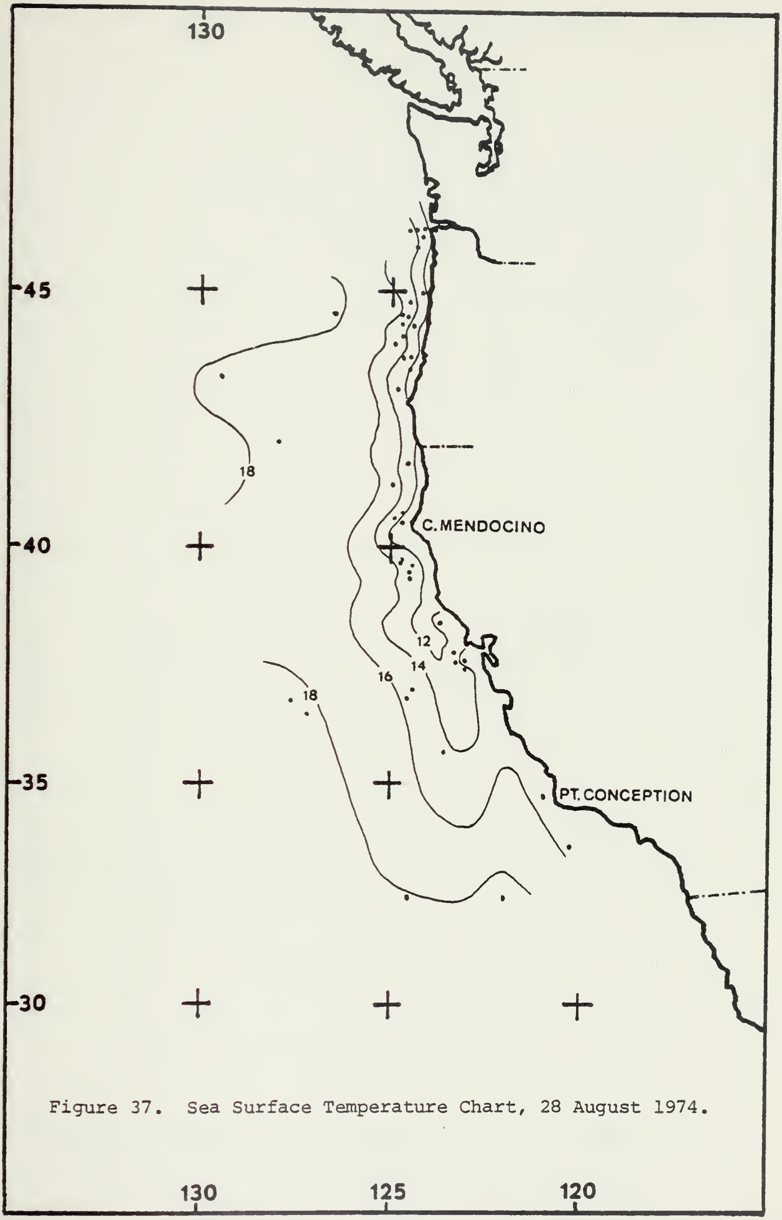

Figure 37. Sea Surface Temperature Chart, 28 August 1974.

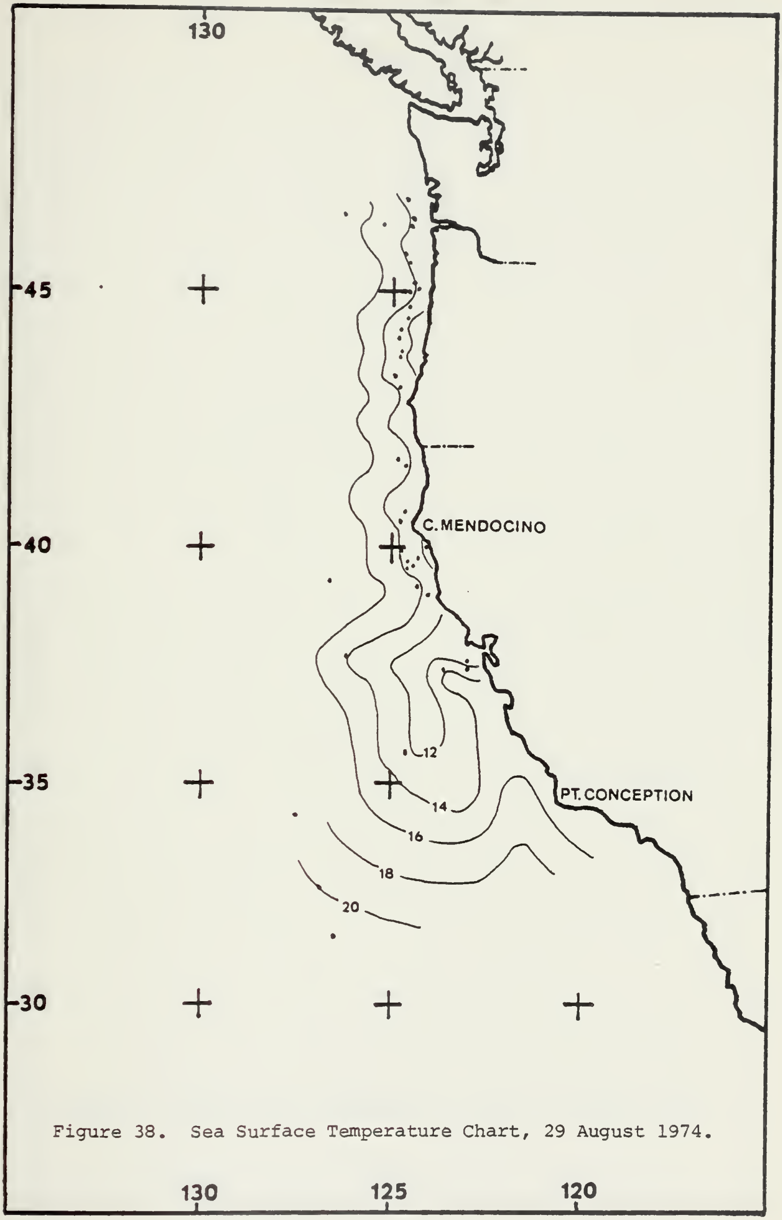

Figure 38. Sea Surface Temperature Chart, 29 August 1974.

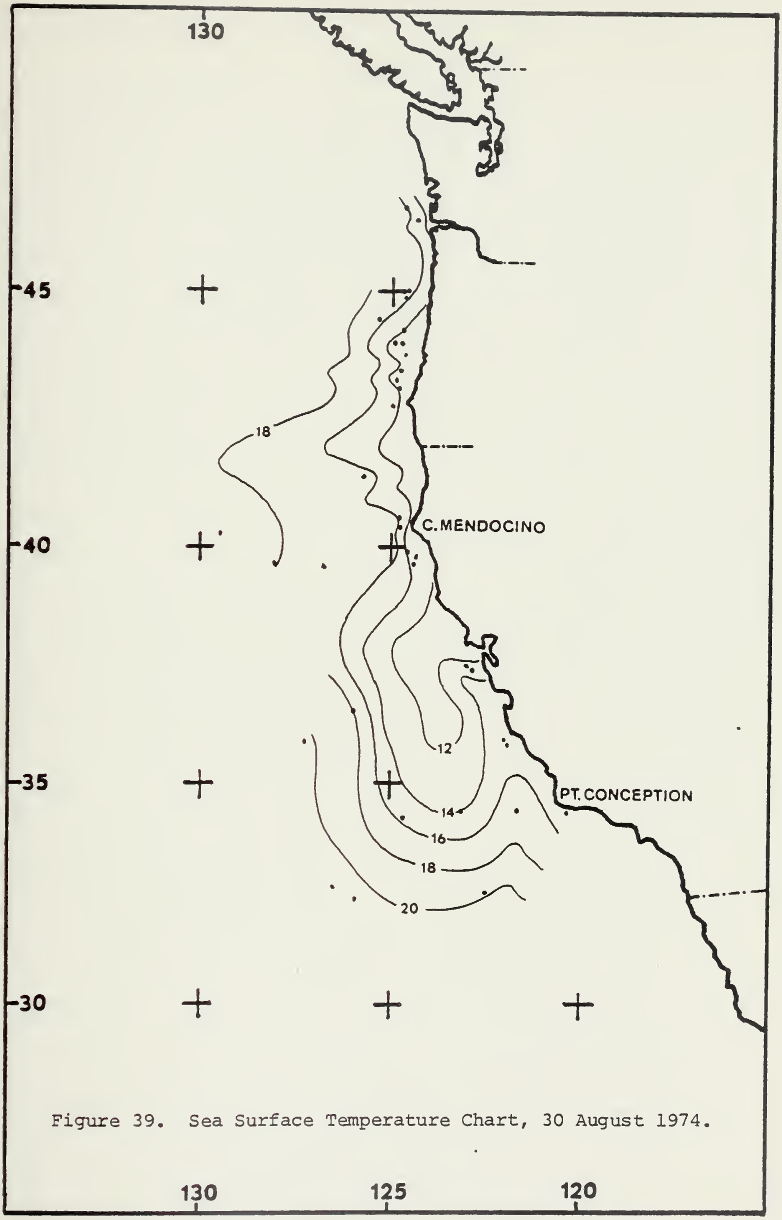

Figure 39. Sea Surface Temperature Chart, 30 August 1974.

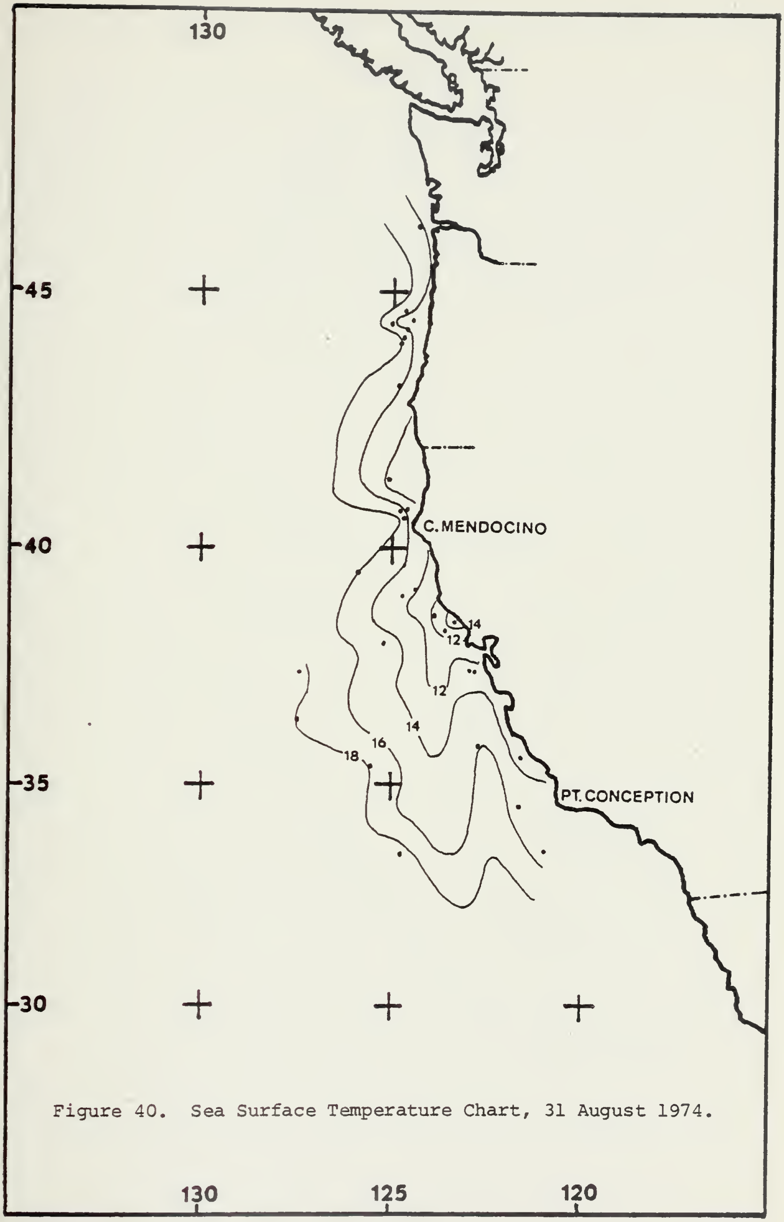

Figure 40. Sea Surface Temperature Chart, 31 August 1974.

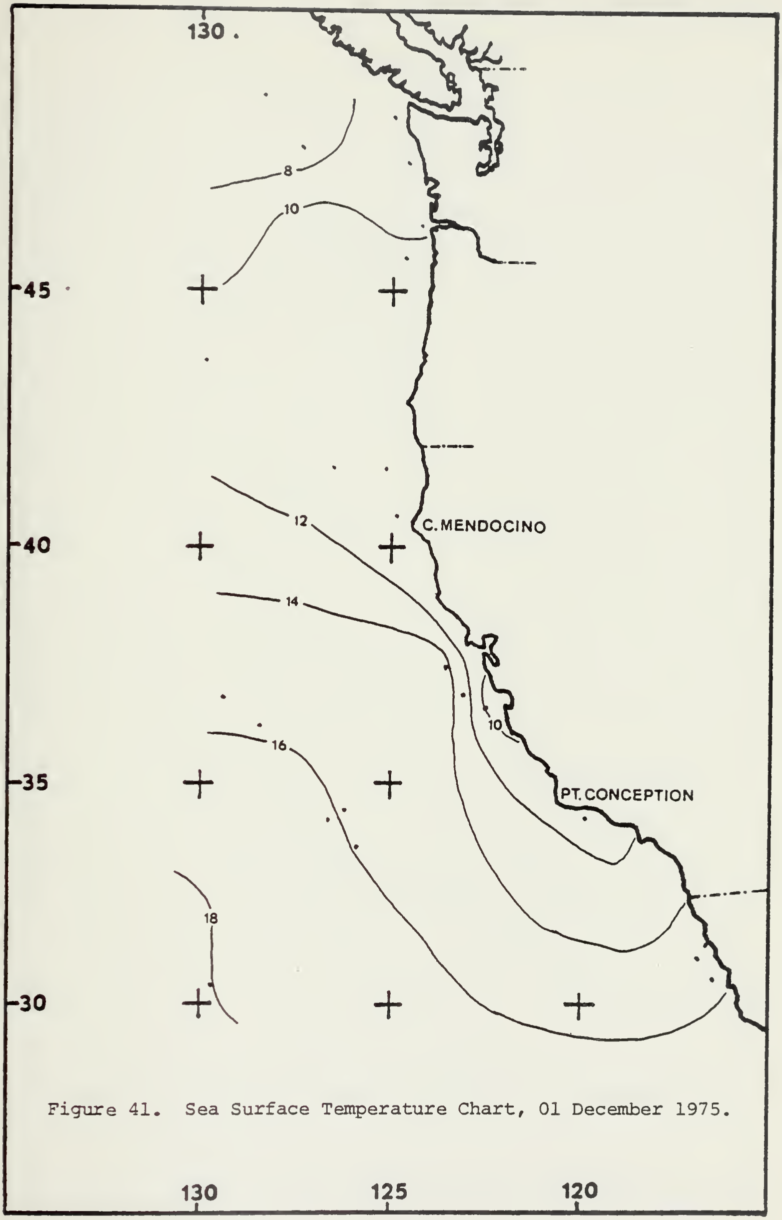

Figure 41. Sea Surface Temperature Chart, 01 December 1975.

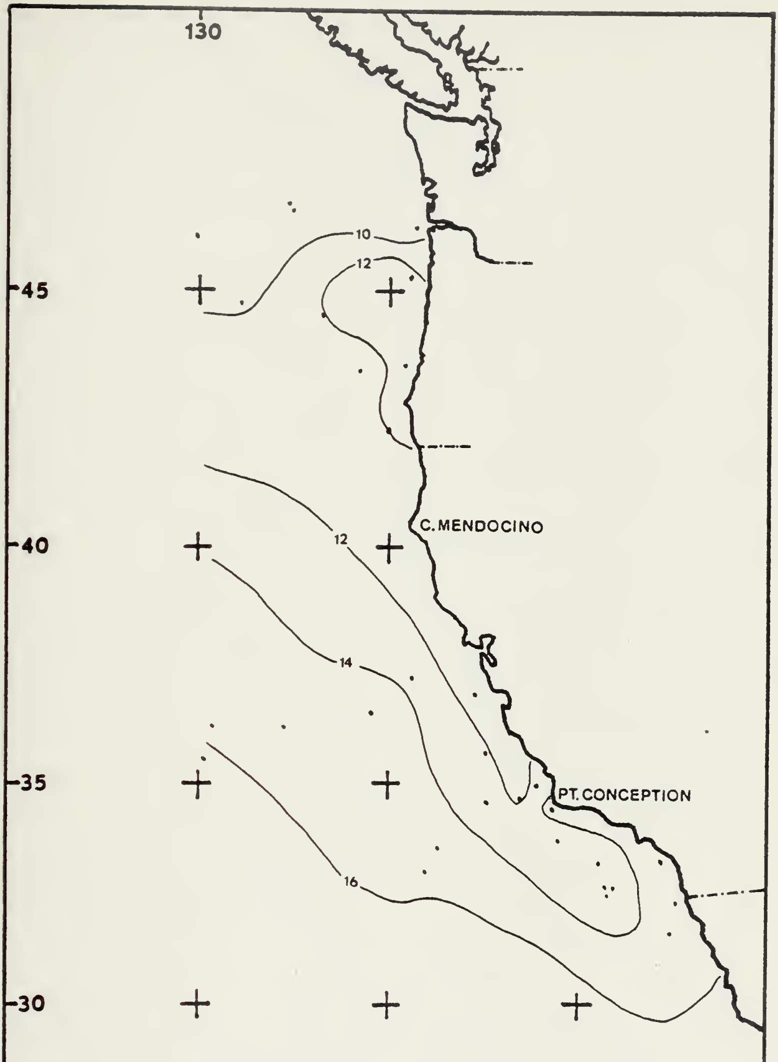

Figure 42. Sea Surface Temperature Chart, 02 December 1975.

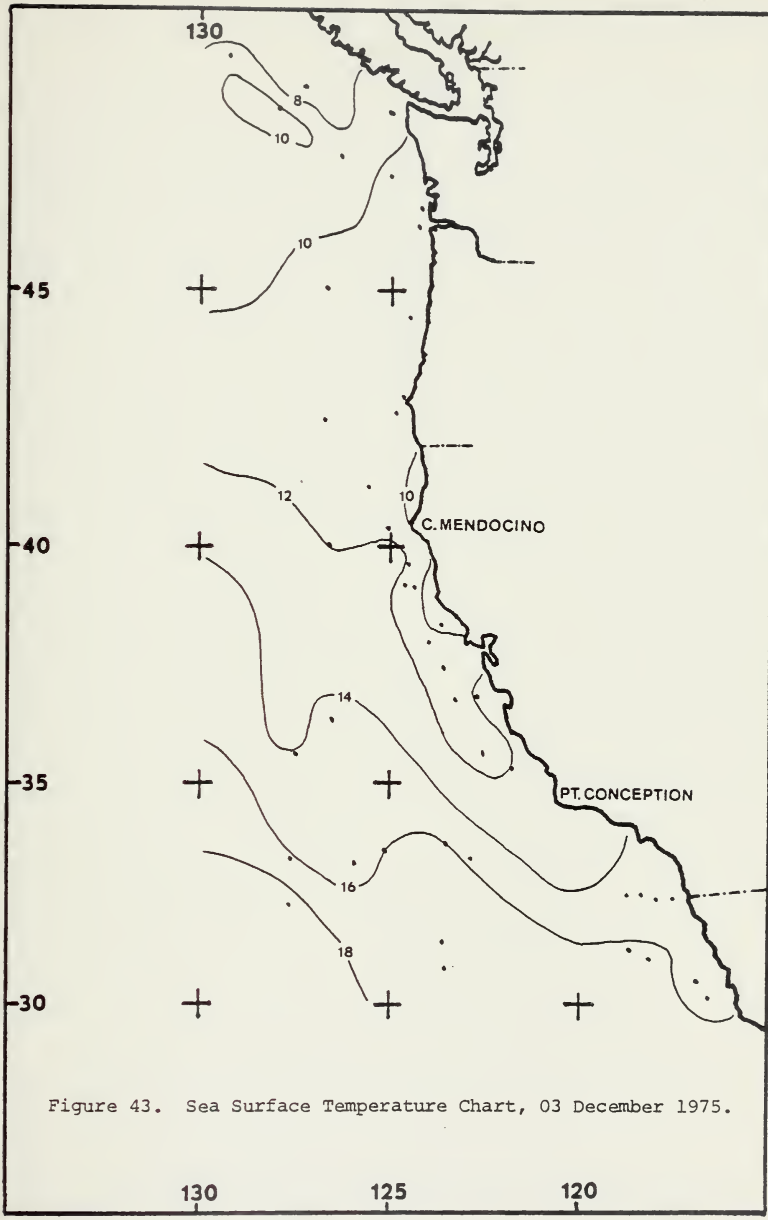

Figure 43. Sea Surface Temperature Chart, 03 December 1975.

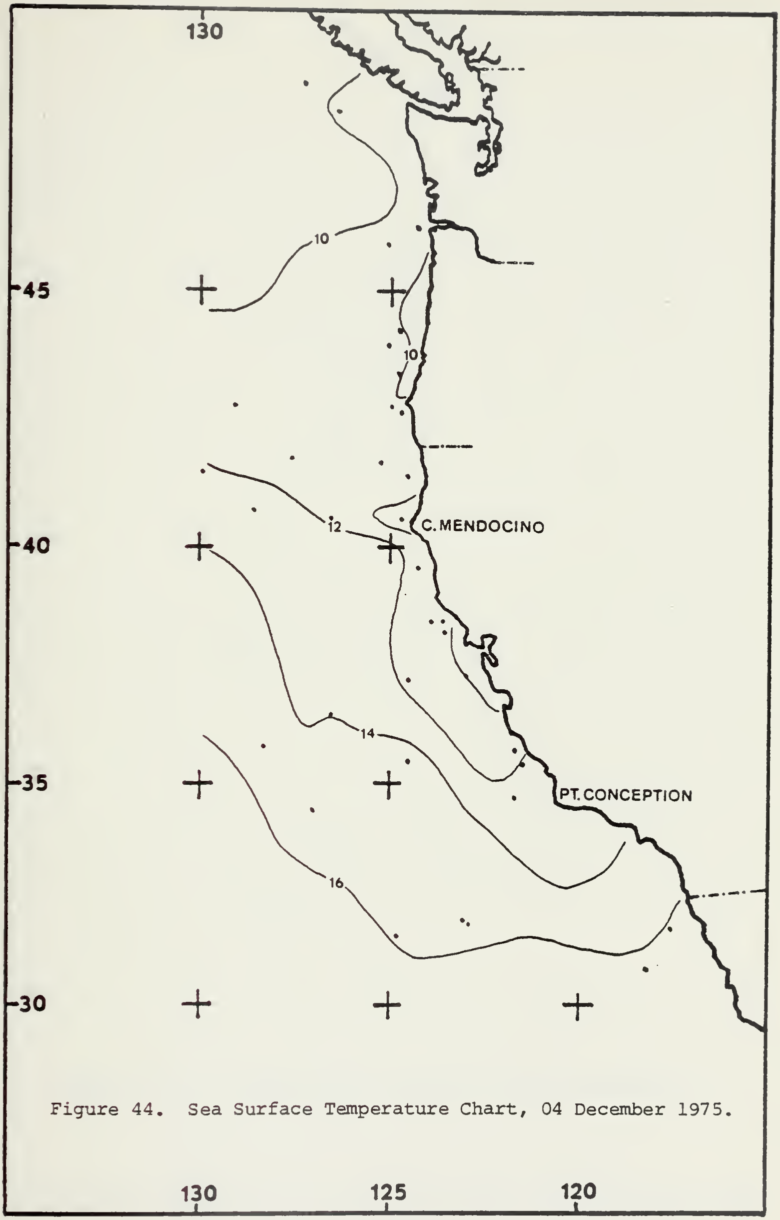

Figure 44. Sea Surface Temperature Chart, 04 December 1975.

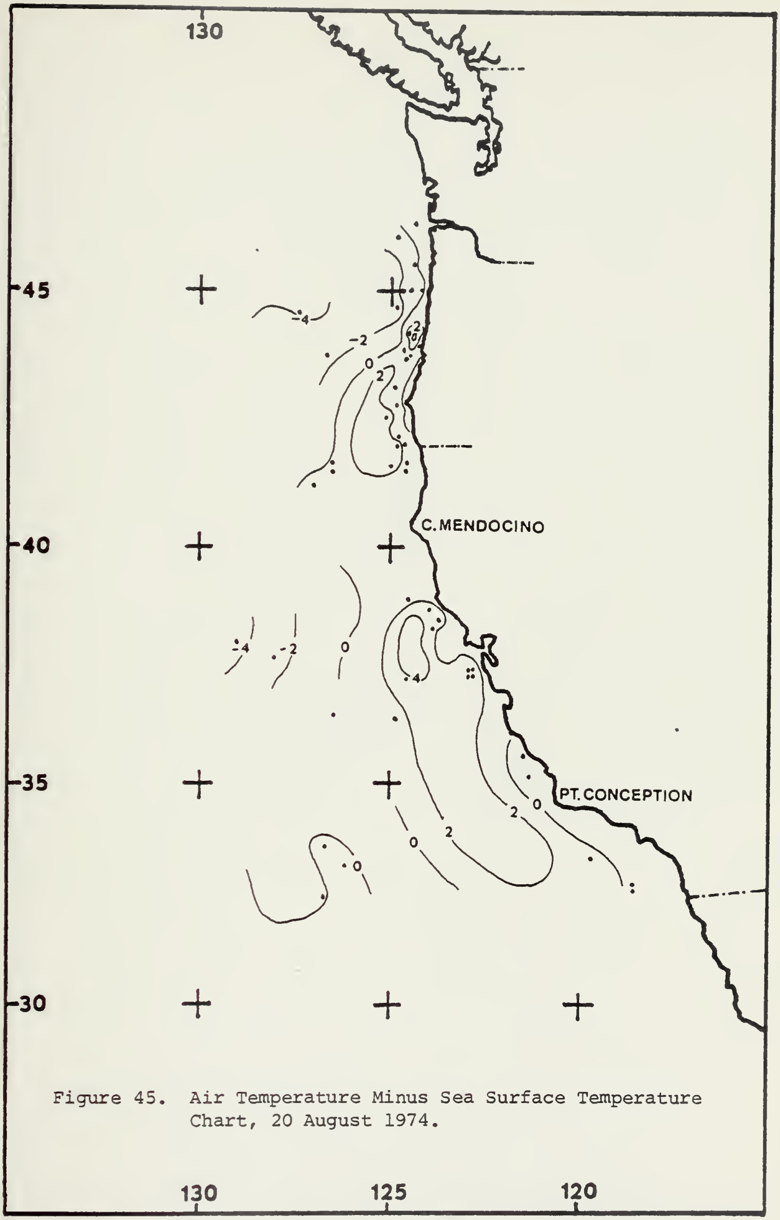

Figure 45. Air Temperature Minus Sea Surface Temperature Chart, 20 August 1974.

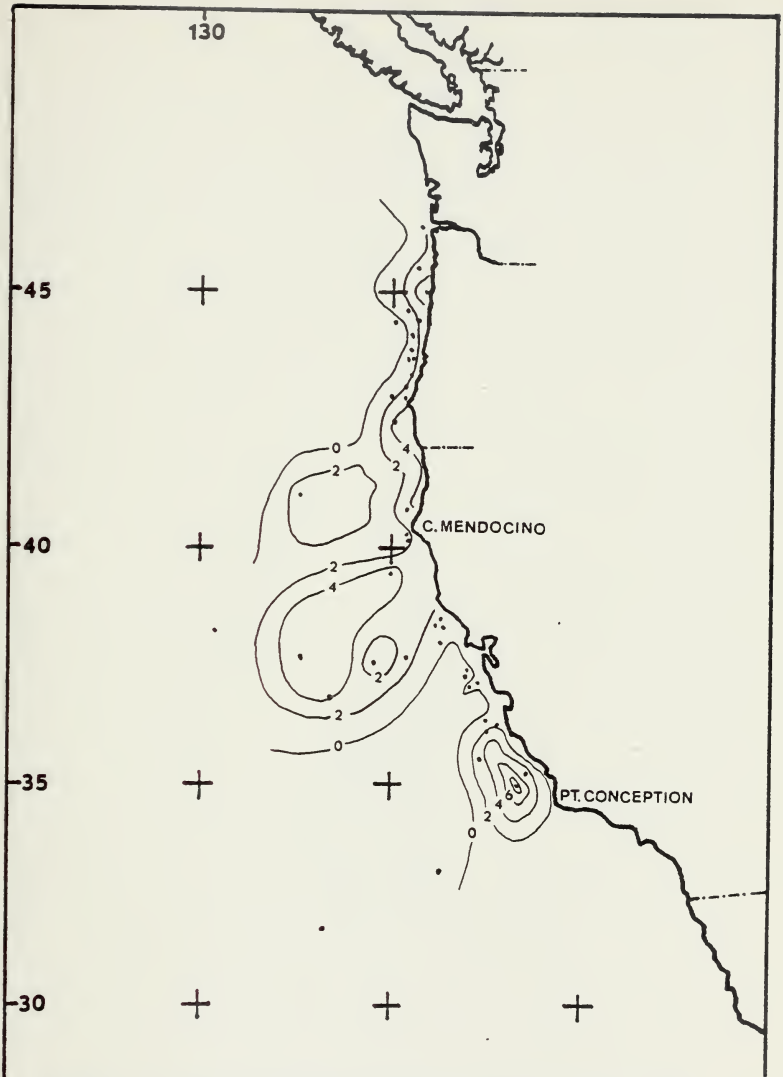

Figure 46. Air Temperature Minus Sea Surface Temperature Chart, 21 August 1974.

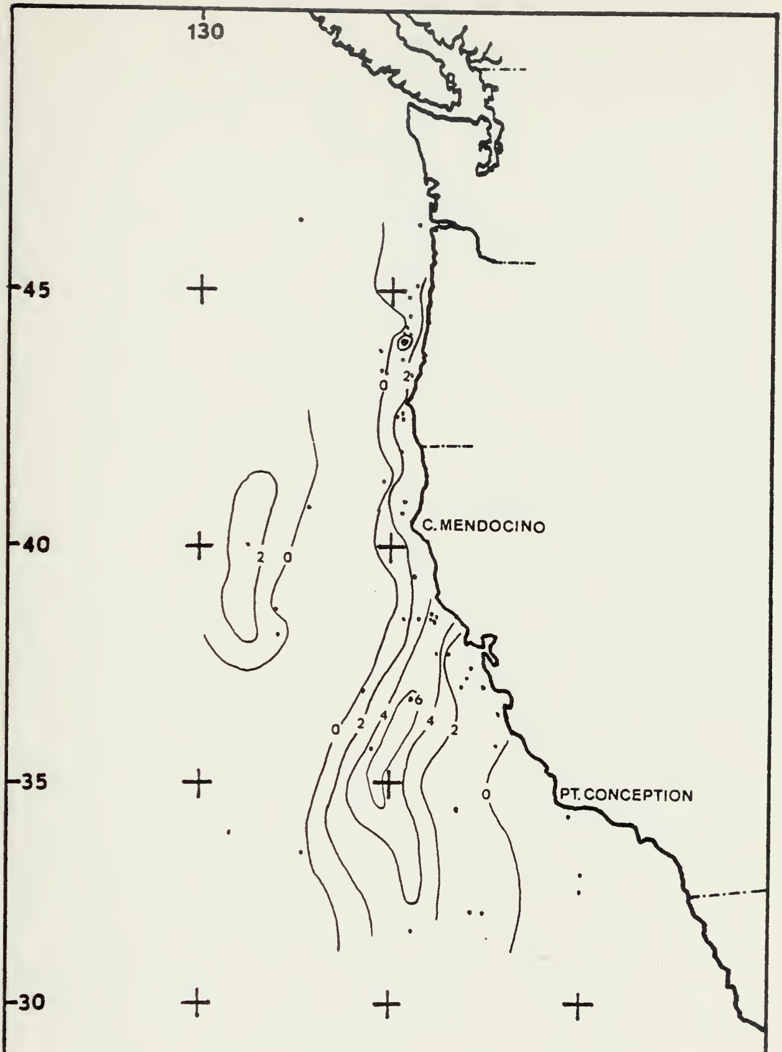

Figure 47. Air Temperature Minus Sea Surface Temperature Chart, 22 August 1974.

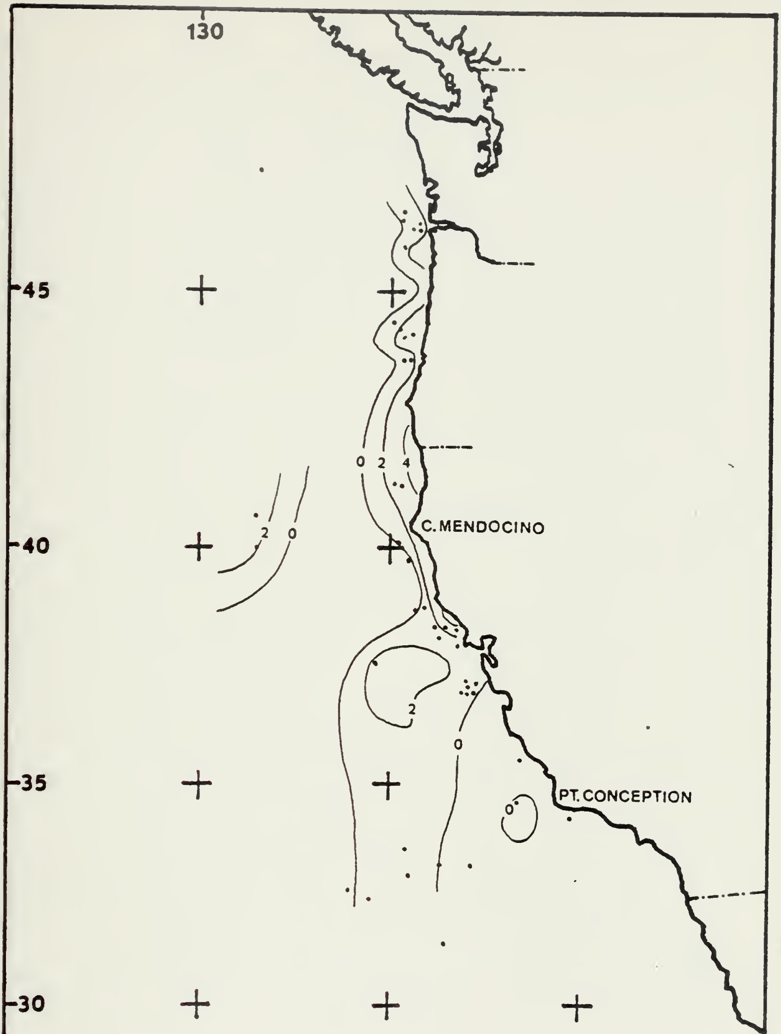

Figure 48. Air Temperature Minus Sea Surface Temperature Chart, 23 August 1974.

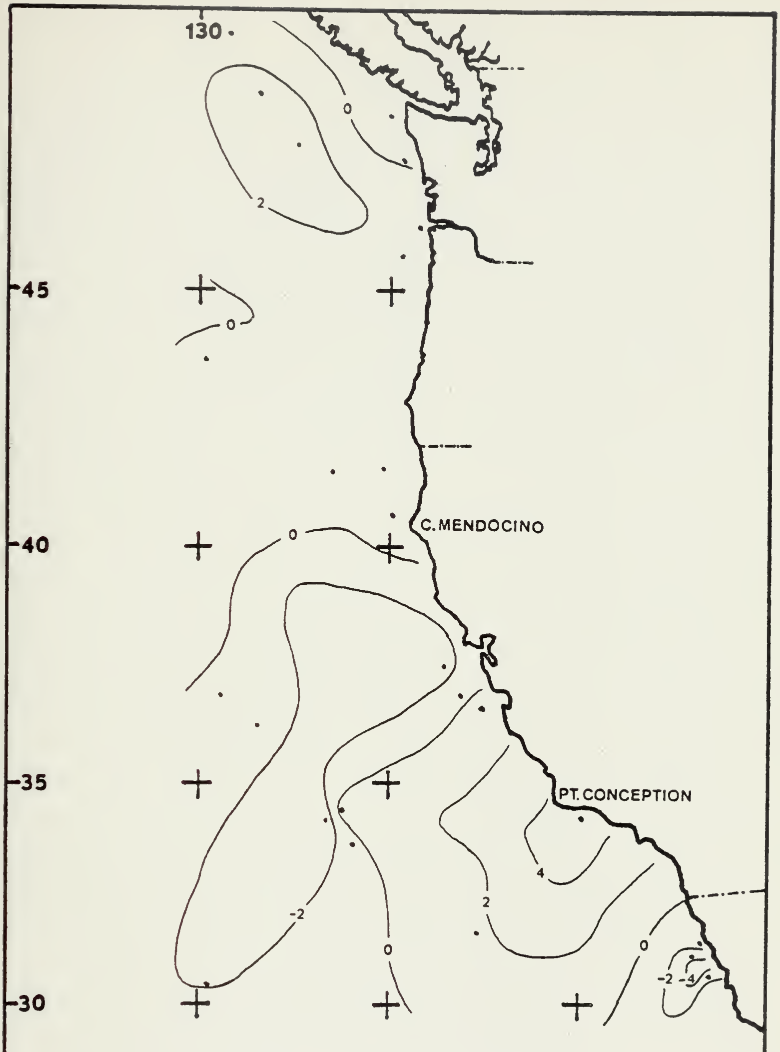

Figure 49. Air Temperature Minus Sea Surface Temperature Chart, 01 December 1975.

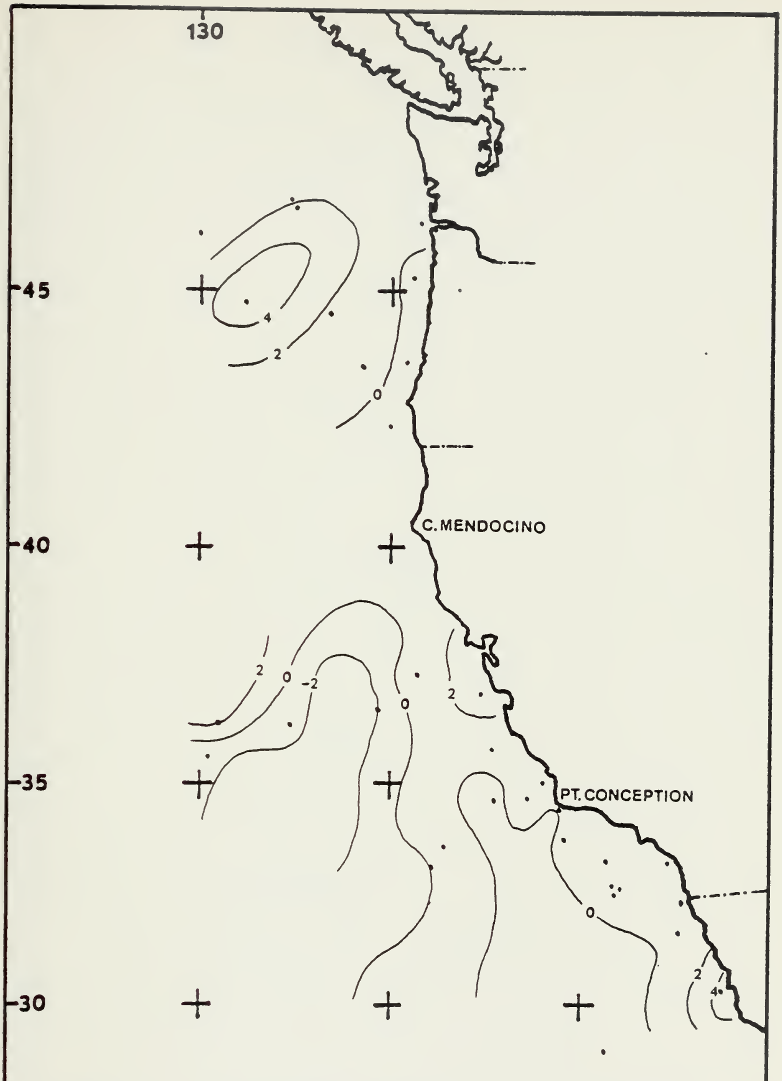

Figure 50. Air Temperature Minus Sea Surface Temperature Chart, 02 December 1975.

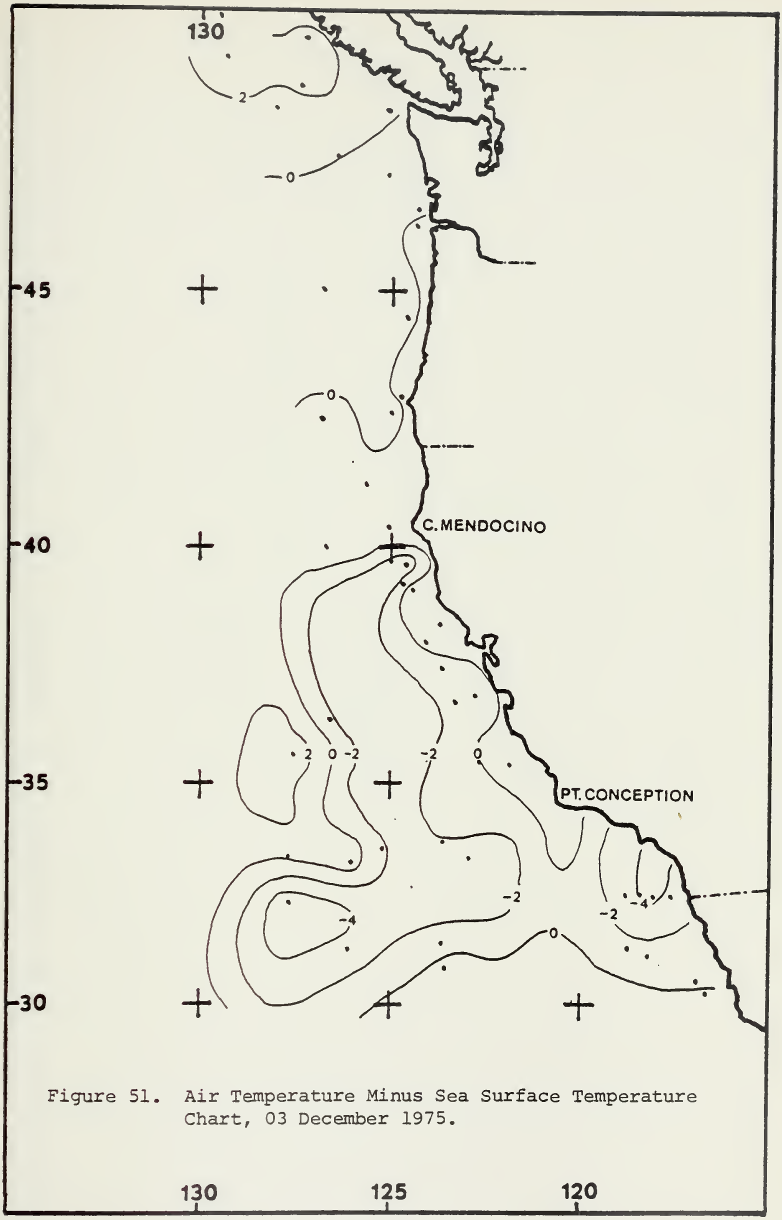

Figure 51. Air Temperature Minus Sea Surface Temperature Chart, 03 December 1975.

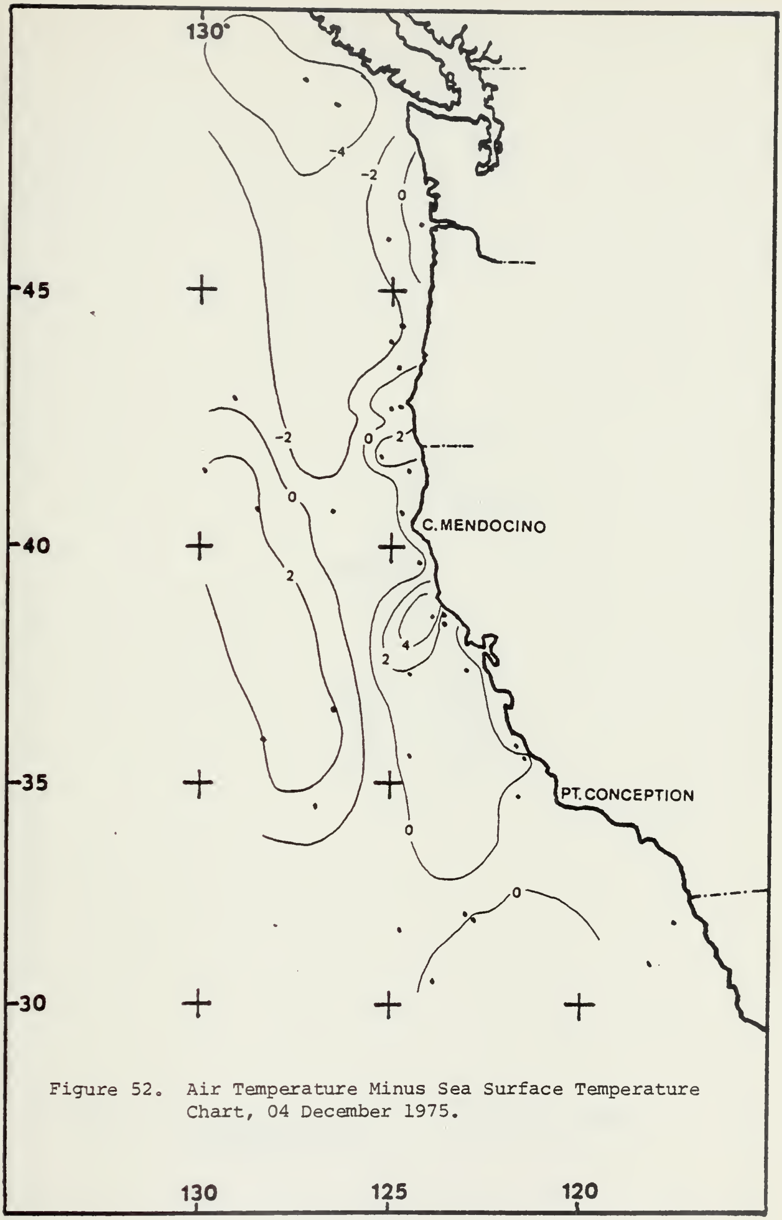

Figure 52. Air Temperature Minus Sea Surface Temperature Chart, 04 December 1975.

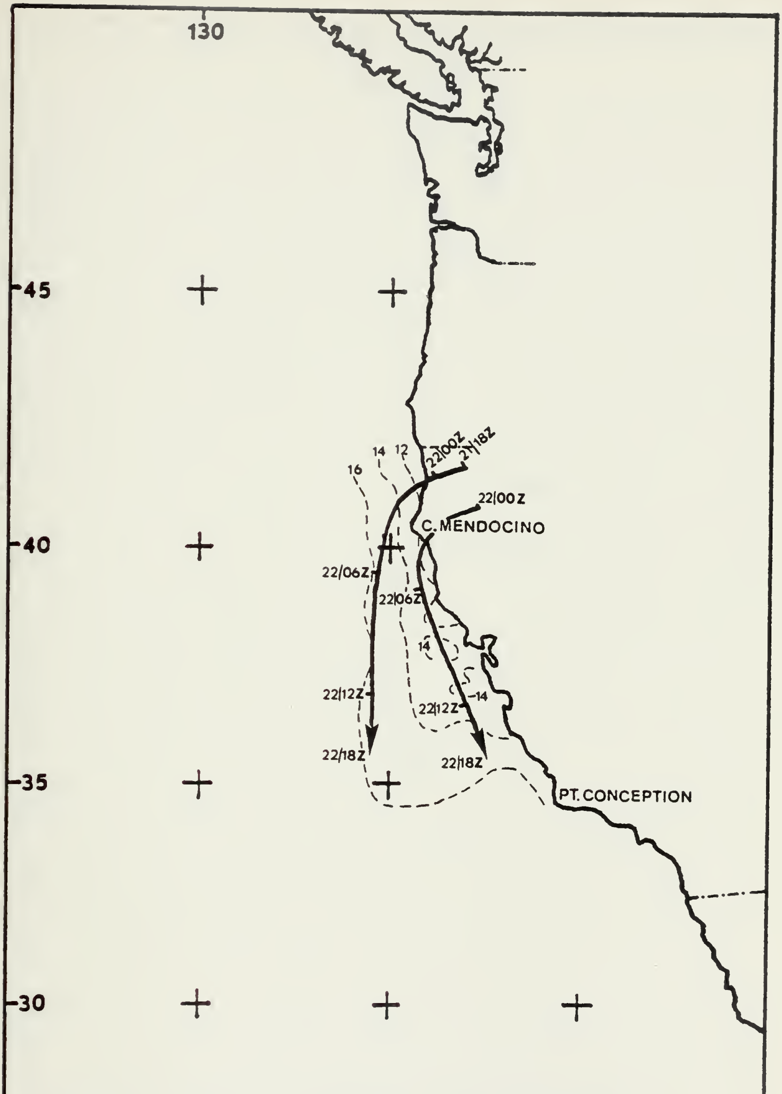

Figure 53. Surface Trajectories, Terminating 1800Z, 22 August 1974.

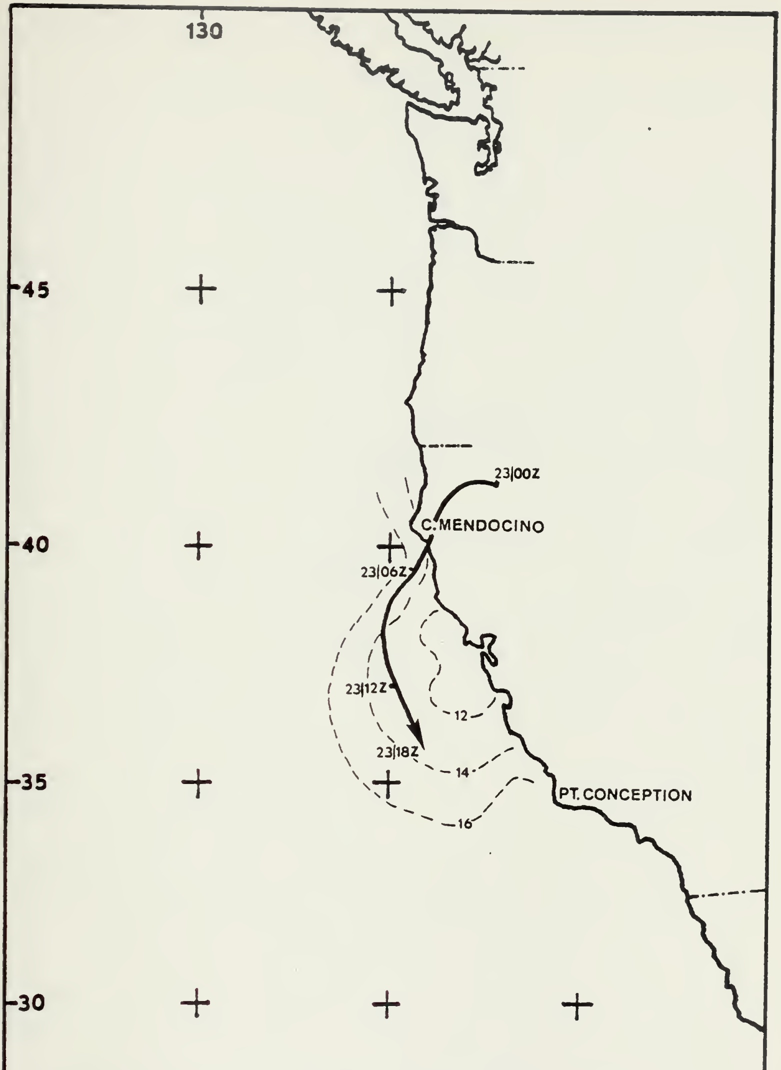

Figure 54. Surface Trajectories, Terminating 1800Z, 23 August 1974.

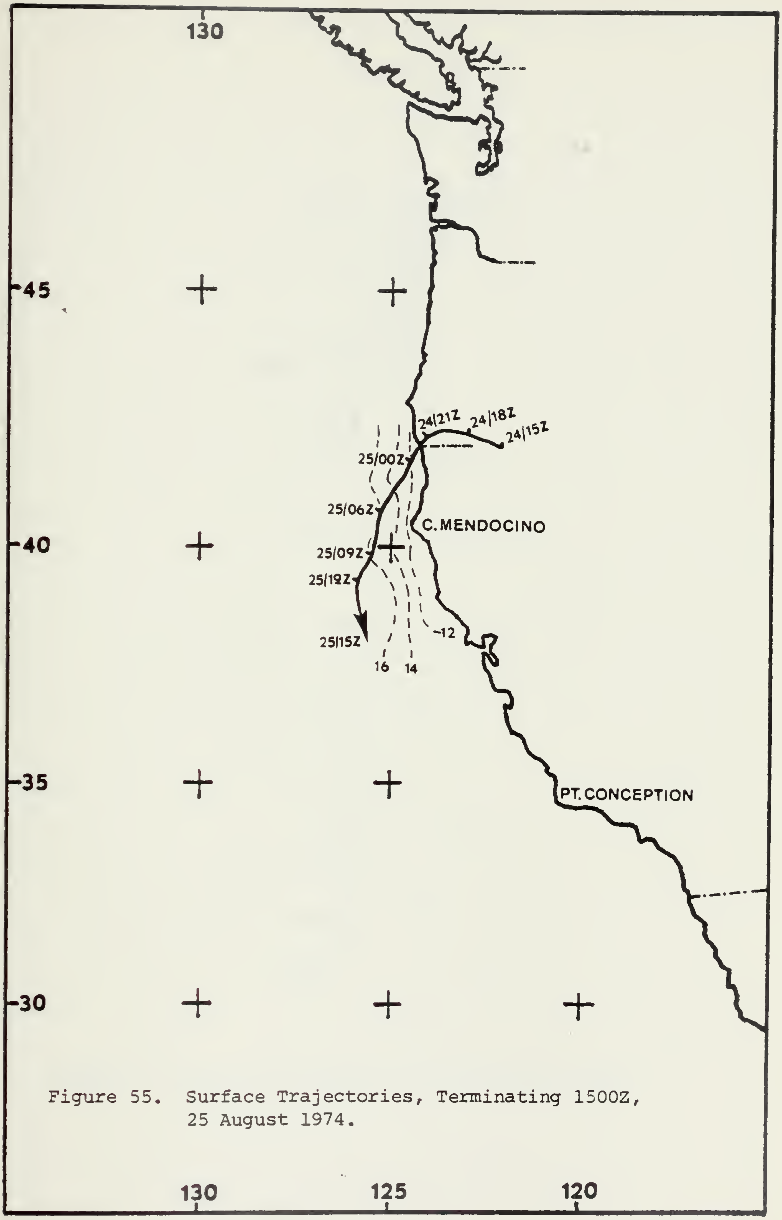

Figure 55. Surface Trajectories, Terminating 1500Z, 25 August 1974.

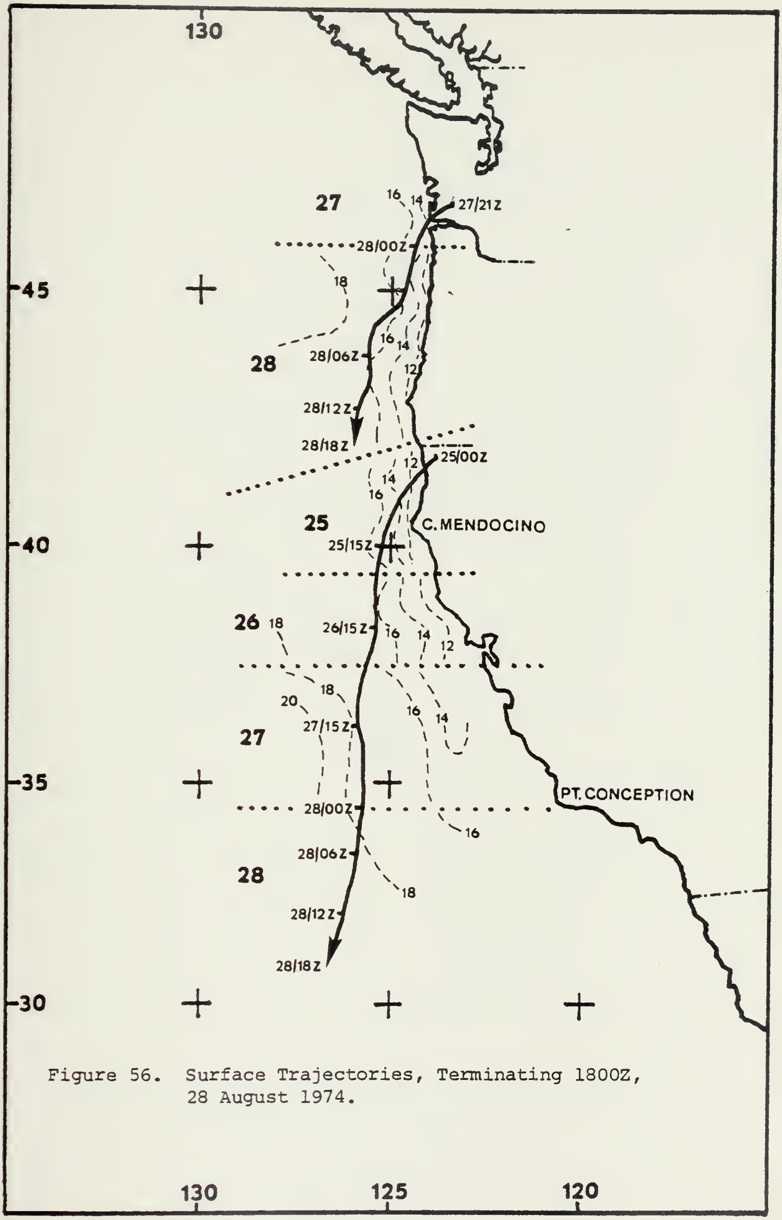

Figure 56. Surface Trajectories, Terminating 1800Z, 28 August 1974.

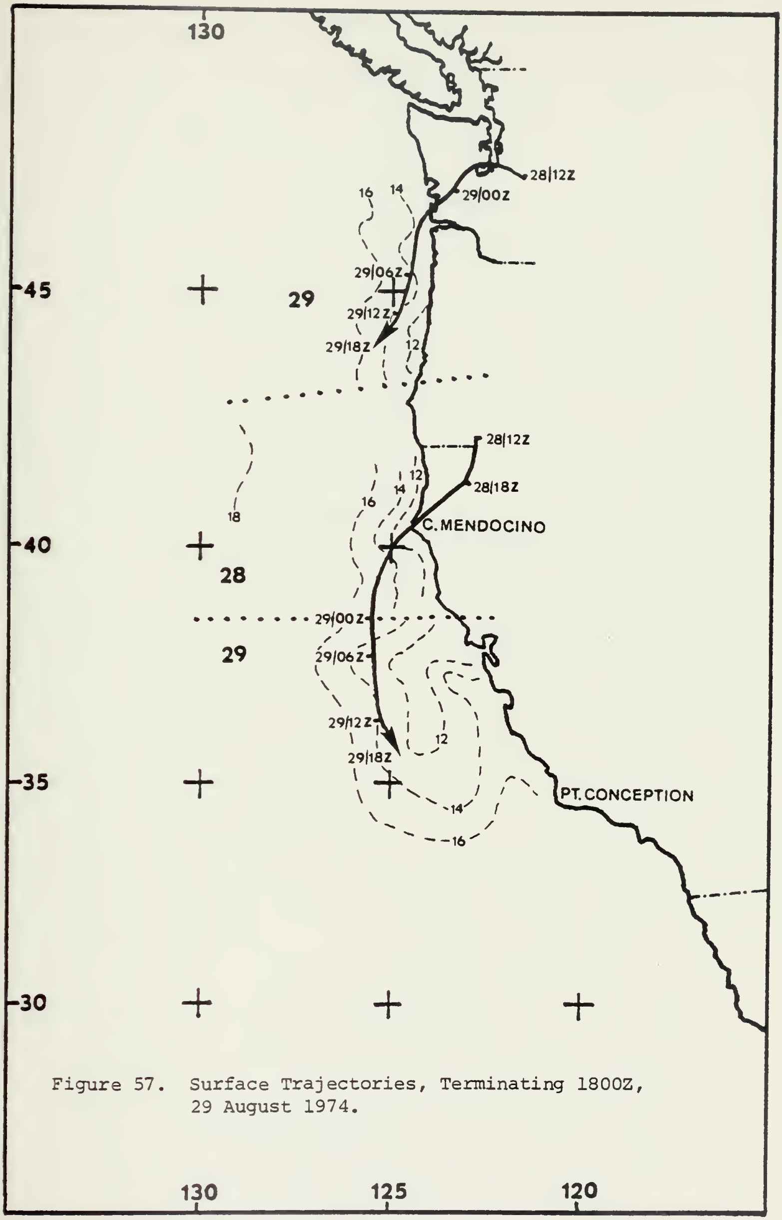

Figure 57. Surface Trajectories, Terminating 1800Z, 29 August 1974.

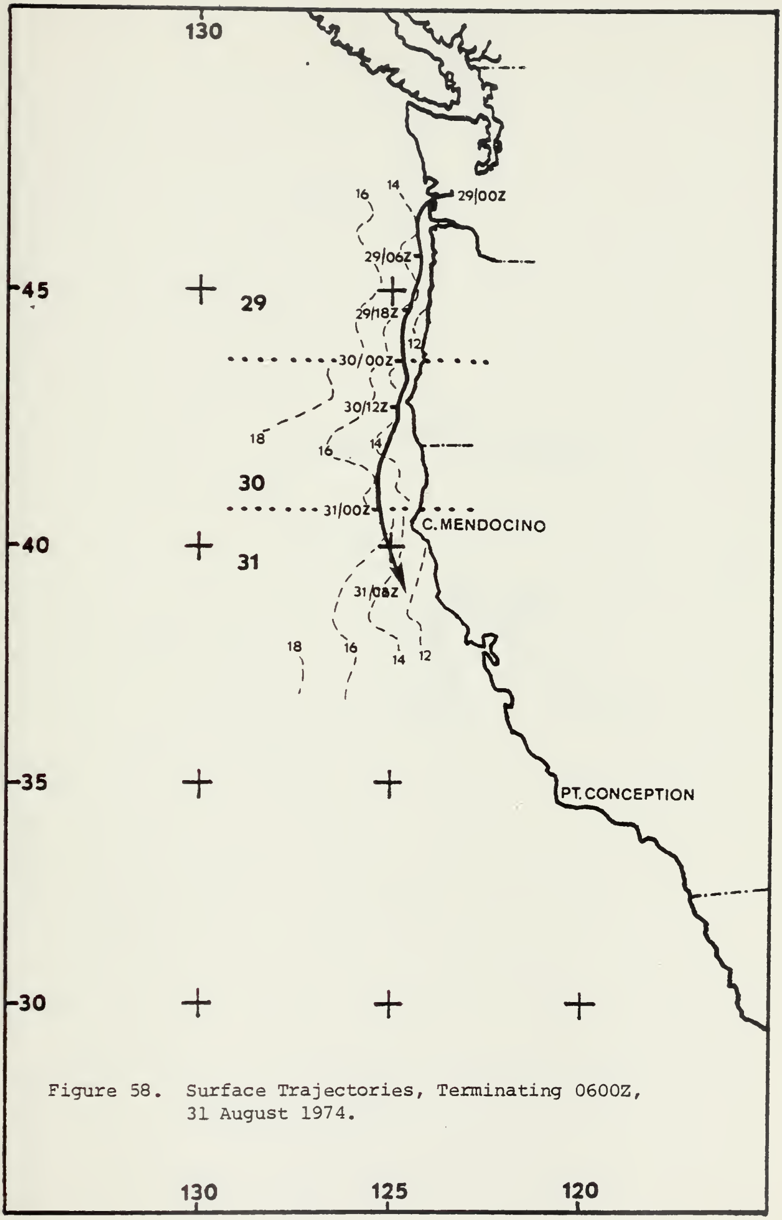

Figure 58. Surface Trajectories, Terminating 0600Z, 31 August 1974.

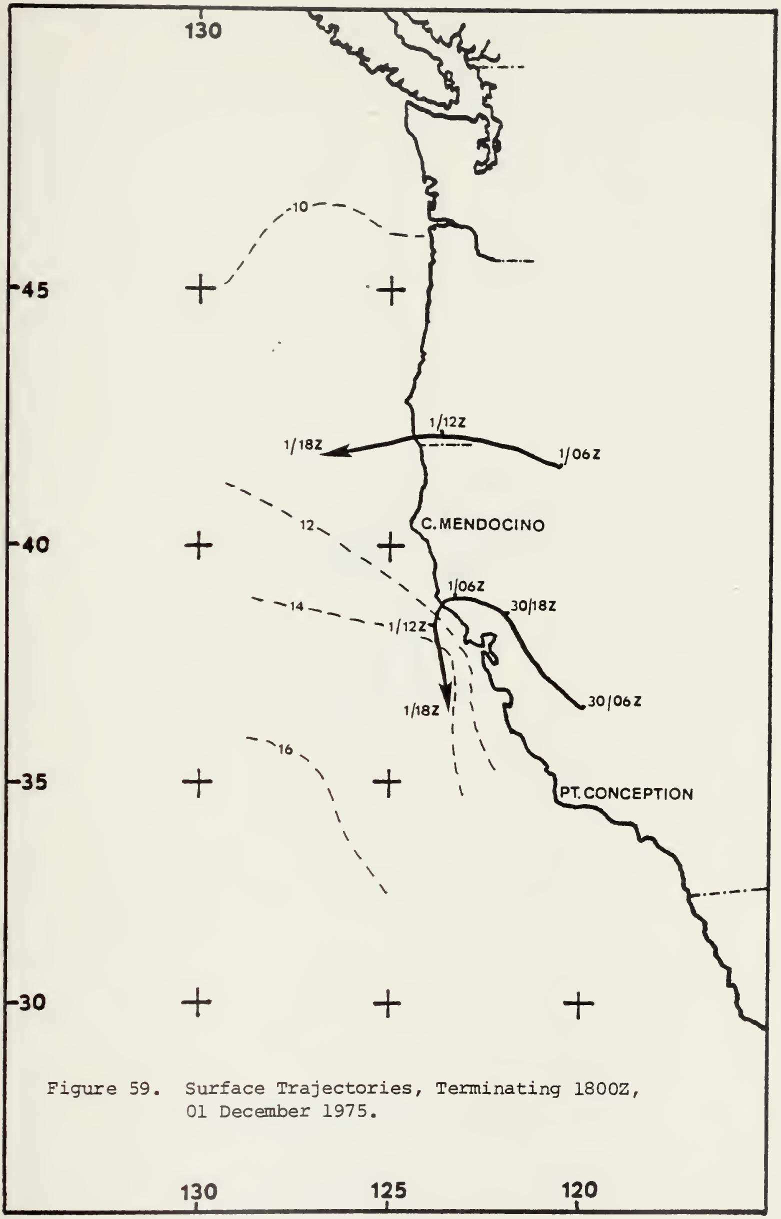

Figure 59. Surface Trajectories, Terminating 1800Z, 01 December 1975.

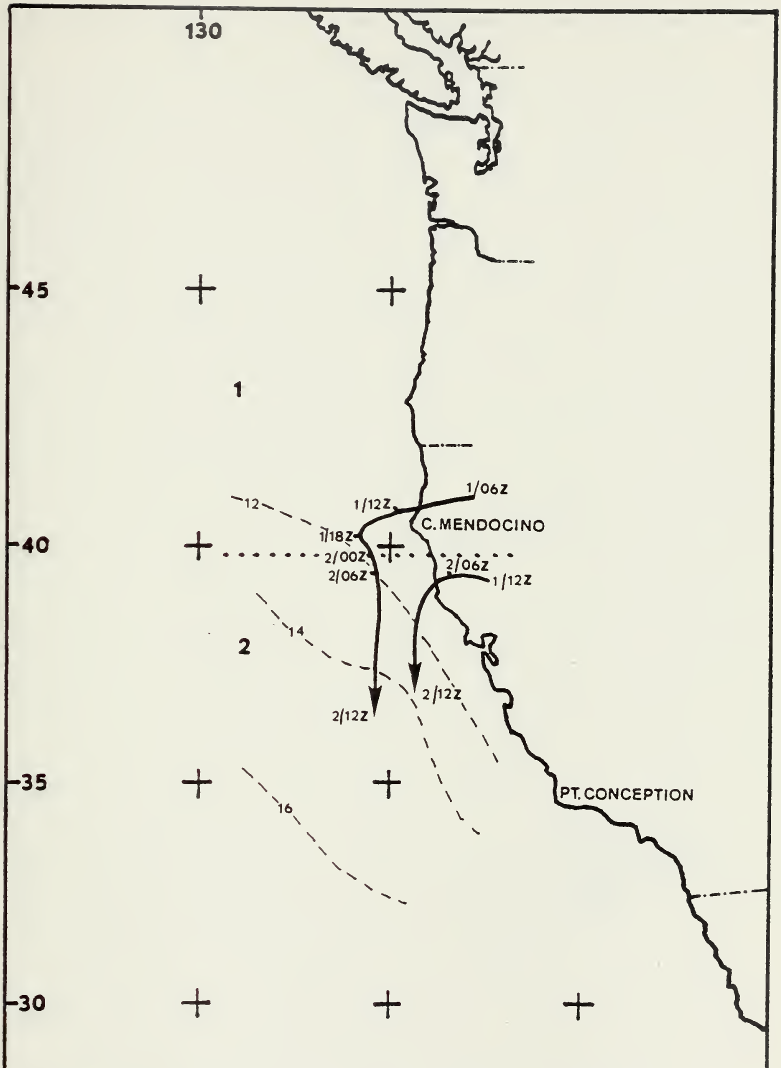

Figure 60. Surface Trajectories, Terminating 1200Z, 02 December 1975.

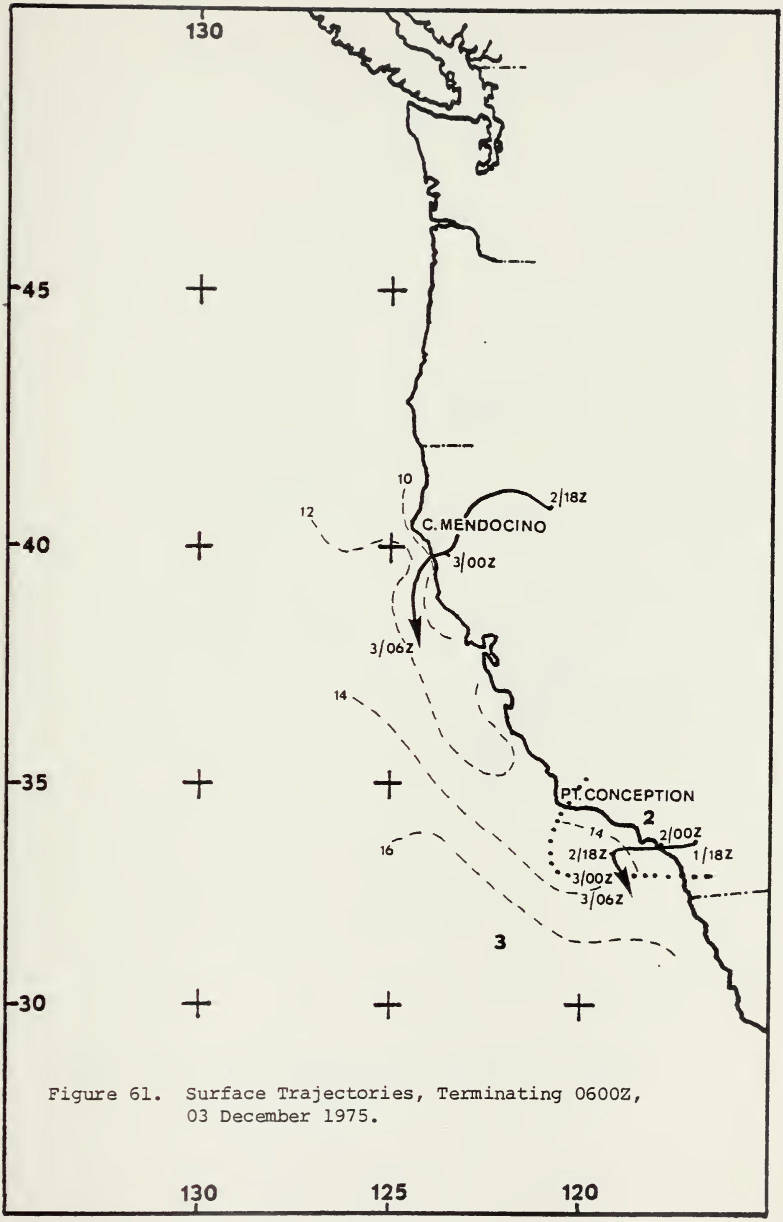

Figure 61. Surface Trajectories, Terminating 0600Z, 03 December 1975.

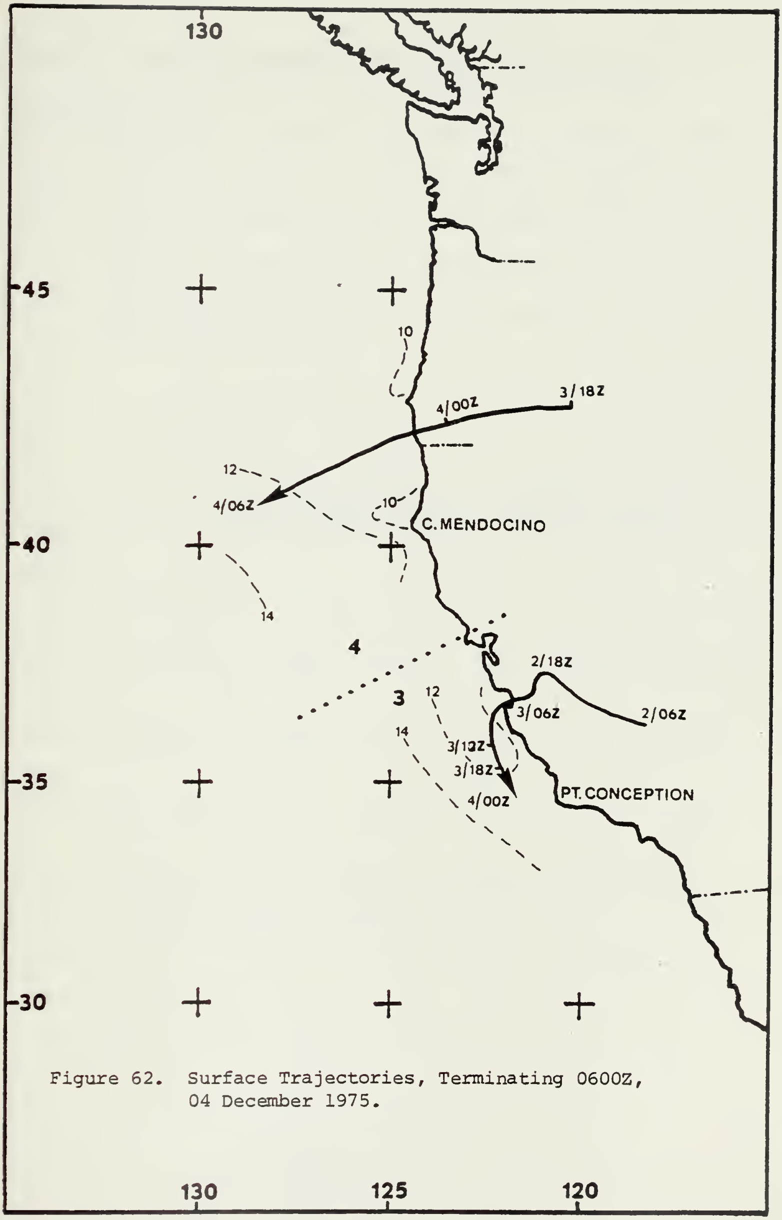

Figure 62. Surface Trajectories, Terminating 0600Z, 04 December 1975.

TABLE I. Visibility-Weather Group Coding Inconsistencies

Type Inconsistency:

A. Too high a visibility (VV) reported with present weather (ww) of 40-49.

B. Too high a visibility (VV) reported with present weather (ww) of 11-12.

C. Too high a visibility (VV) reported with present weather (ww) of 10.

D. Too low a visibility (VV) reported with present weather (ww) of 28.

E. No visibility restriction with a reported visibility of less than 1000 meters.

	19 AUG - 5 SEPT 1974			1-4 DEC 1975		
ww code	Number of times reported	Related inconsistency		Number of times reported	Related inconsistency	
		Type	No./%		Type	No./%
40-49	167	A	82/49	27	A	24/89
11-12	15	B	14/93	2	B	2/100
10	67	C	14/21	2	C	2/100
28	19	D	3/16	1	D	0/0
-	-	E	1	-	E	1
Total inconsistencies			114			29

TABLE II. Abridged version of internationally used weather-code figures and definitions for reporting present and past weather in the surface synoptic report (U. S. Departments of Commerce, Defense, and Transportation, 1969), from Willms, 1975.

Present Weather

Code Value	Definition
00-03	Characteristic change of the state of the sky (cloud) during the past hour.
04-09	Haze, dust, sand, or smoke.
10	Deep light fog.
11-12	Shallow heavy fog.
13-17	Lightning, thunder or precipitation within sight, not reaching the ground.
18-19	Squall(s), funnel cloud(s) during the past hour.
20-29	Precipitation, fog, or thunderstorms at the station during the preceding hour but not at time of observation.
30-39	Duststorm, sandstorm, drifting or blowing snow.
40-49	Deep heavy fog at the time of observation, (visibility less than 1 kilometer).
50-59	Precipitation at the station.
60-69	Rain.
70-79	Solid precipitation not in showers.
80-99	Showery precipitation or precipitation with current or recent thunderstorms.

Past Weather

Code Value	Definition
0	Cloud covering 1/2 or less of sky throughout the period.
1	Cloud covering more than 1/2 of sky during part of period.
2	Cloud covering more than 1/2 of sky throughout the period.
3	Sandstorm, or duststorm, blowing snow.
4	Heavy fog, thick haze, or smoke.
5	Drizzle.
6	Rain.
7	Snow, rain and snow mixed, or ice pellets.
8	Shower(s).
9	Thunderstorm, with or without precipitation.

Visibility

Code Value	
90	less than 50 m
91	0-199 m
92	200-499 m
93	500 m - .99 km
94	1 - 1.99 km
95	2 - 3.99 km
96	4 - 9.99 km
97	equal to or greater than 10 km

TABLE III. SSR-75 scheme format: fog/no fog categories and fog duration times for six-hour marine synoptic reports using combinations of the visibility-weather group elements. (Willms, 1975).

SSR-75 FOG DURATION CATEGORIES	SYNOPTIC CODE VALUES			HOURS OF FOG ASSIGNED
	VISIBILITY	PRESENT WEATHER	PAST WEATHER	
10	*	40-49	4	5.5
15	*	40-49	5	4.3
20	*	10	4	5.1
22	*	11,12	4	3.0
24	*	10	5	3.0
26	*	11,12	5	2.0
30	90-93	*	4	4.7
31	90-93	**	4	3.0
32	94	*	4	3.8
33	94	**	4	3.0
35	90-93	*	5	3.8
36	90-93	**	5	2.0
37	94	*	5	1.2
38	94	**	5	1.0
40	*	28	4	5.3
45	*	28	5,6	3.3
50	*	40-49	6	3.6
60	*	10	6	2.6
65	*	11,12	6	1.0
70	90-93	*	6	2.9
71	90-93	**	6	1.0
72	94	*	6	1.0
73	94	**	6	1.0
80	*	40-49	2	4.0
90	*	10	2	3.5
95	*	11,12	2	1.0
100	90-93	*	2	2.5
102	94	*	2	1.3
110	*	28	2	4.6
120	*	*	4	3.1
130	*	40-49	*	3.6
140	*	10	*	2.6
145	*	11,12	*	1.0
150	90-93	*	*	1.0
152	94	*	*	1.0
160	*	28	*	3.3
170	Fog according to visibility in categories 100,102, 150 and 152 but disqualified by heavy present weather codes			0.0
175	95,96	*	0-3,7-9	0.6
180	All reports not fitting above categories			

* Denotes any synoptic code other than one listed in column.

** Denotes heavy present-weather codes: 30-39,62-65,67,69,72-75,81,82, 84,86,88,90-99.

TABLE IV. SSR-scheme format: listing and description of the elements of the visibility-weather group in the synoptic reports used to identify the existence of marine fog. (Willms, 1975).

Fog related weather element	Symbolic letter(s)	Code figure(s)	Description	Depth of fog at sea (ft)	Visibility (km)	Related VV code figure(s)	Time of Occurrence
Present weather	ww	10	deep light fog at station	≥ 33	1-10	93-96	At observation
		11	shallow heavy fog at station	<33	< 1	90-93	At observation
		12	shallow heavy fog at station	<33	< 1	90-93	At observation
		28	heavy fog at station	≥ 33	< 1*	90-93*	Within one hour of observation but not at observation
		40	heavy fog at a distance from station	≥ 33	< 1	90-93	At observation
		41-49	heavy fog at station	≥ 33	< 1	90-93	At observation
Past weather	W	4	heavy fog or haze or smoke	≥ 33	< 1*	90-93*	In the period one to six hours before observation
Horizontal visibility	VV	90-94**			< 2		At observation
		95,96**			2-10		At observation

* At time of visibility restriction indicated by present or past weather code figure.

** Visibility codes used to identify fog when ww(W) is not 10, 11, 12, 28 or 40-49(4).

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